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# INVESTIGATION OF TEST METHODS, MATERIAL PROPERTIES, AND PROCESSES FOR SOLAR CELL ENCAPSULANTS

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JPL Contract 954527
Project 6072.1

For

JET PROPULSION LABORATORY
4800 Oak Grove Drive
Pasadena, California 91103



ENCAPSULATION TASK OF THE LOW-COST SILICON SOLAR ARRAY PROJECT

The JPL Low-Cost Silicon Solar Array Project is sponsored by the U. S. Department of Energy and forms part of the Solar Photovoltaic Conversion Program to initiate a major effort toward the development of low-cost solar arrays. This work was performed for the Jet Propulsion Laboratory, California Institute of Technology, by agreement between NASA and DOE.

P. B. Willis
B. Baum
H. S. Schnitzer

By

SPRINGBORN LABORATORIES, INC.
Enfield, Connecticut 06082

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# I. SUMMARY

Springborn Laboratories is engaged in a study of evaluating potentially useful encapsulating materials for Task 3 of the Low-Cost Silicon Solar Array project (LSA) funded by DOE. The goal of this program is to identify, evaluate, and recommend encapsulant materials and processes for the production of cost-effective, long-life solar cell modules.

This report presents the results of a cost analysis of candidate potting compounds for long life solar module encapsulation. Additionally, the two major encapsulation processes, sheet lamination and liquid casting, are costed on the basis of a large scale production facility. The costs found for these items are presented as follows:

| Pottant | Manufacturing Cost \$/ft$^2$ |
|---|---|
| EVA, sheet, clear | \$ 0.09 |
| EVA, sheet, pigmented | 0.10 |
| EPDM, sheet, clear | 0.10 |
| Aliphatic urethane, syrup | 0.18 |
| PVC Plastisol | 0.10 |
| Butyl acrylate, syrup | 0.06 |
| Butyl acrylate, sheet | 0.08 |

| Encapsulation Process Cost | |
|---|---|
| Sheet lamination technique | \$0.87 |
| Liquid casting technique | 0.81 |

## II. INTRODUCTION

The goal of this program is to identify and evaluate encapsulation materials and processes for the protection of silicon solar cells for service in a terrestrial environment.

Encapsulation systems are being investigated consistent with the DOE objectives of achieving a photovoltaic flat-plate module or concentrator array at a manufactured cost of $0.70 per peak watt (1980 dollars). The project is aimed at establishing the industrial capability to produce solar modules within the required cost goals by the year 1986.

To insure high reliability and long-term performance, the functional components of the solar cell module must be adequately protected from the environment by some encapsulation technique. The potentially harmful elements to module functioning include moisture, ultraviolet radiation, heat build-up, thermal excursions, dust, hail, and atmospheric pollutants. Additionally, the encapsulation system must provide mechanical support for the cells and corrosion protection for the electrical components.

Module design must be based on the use of appropriate construction materials and design parameters necessary to meet the field operating requirements, and to maximize cost/performance.

Assuming a module efficiency of ten percent, which is equivalent to a power output of 100 watts per $m^2$ in midday sunlight, the capital cost of the modules may be calculated as $70.00 per $m^2$. Out of this cost goal only 5.4 percent is available for encapsulation due to the high cost of the cells. The encapsulation cost allocation may then be stated as $3.80 per $m^2$ ($0.35 per $ft^2$) which includes all coatings, pottants and mechanical supports for the solar cells.

Assuming the flat-plate collector to be the most efficient design, three different basic design variations have been considered: (a) Substrate bonded, with the cells supported from the underside, (b) Superstrate bonded, with the cells supported on the topside with a rigid transparent material, and (c) laminated, with the cells encapsulated in a single material.

Solar cell modules are presently envisioned as being composed of six basic construction elements. These elements are (a) outer covers; (b) structural and transparent superstrate materials; (c) pottants; (d) substrates; (e) back covers; and (f) adhesives. Current investigations are concerned with identifying and utilizing materials or combinations of materials for use as each of these elements.

Extensive surveys have been conducted into many classes of materials in order to identify a compound or class of compounds optimum for use as each construction element[a].

The results of these surveys were also useful in generating first-cut cost allocations for each construction element, which are estimated to be as follows (1980 dollars):

| Construction Elements | Cost Allocation* ($/Ft$^2$) |
|---|---|
| Substrate/Superstrate | 0.19 |
| Pottant | 0.08 |
| Adhesive | 0.06 |
| Outer cover | 0.01 |
| Back cover | 0.07 |

*Allocation for combination of construction elements: $0.35/ft$^2$; $3.80/m$^2$.

From this work, it became possible to identify a small number of materials which had the highest potential as candidate low cost encapsulation materials. The following chart shows the materials of current interest and their anticipated functions:

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(a) Willis, P., Baum, B., Encapsulation Task 3rd Annual Report, DOE/JPL-954527, Springborn Laboratories, Inc., Enfield, Conn., June 1979

Candidate Encapsulation Materials

| Structural Element Superstrate Design | Elastomeric Pottant | Cover | Adhesives |
|---|---|---|---|
| Soda-Lime Glass | Ethylene/vinyl acetate<br>Ethylene/propylene diene<br>Polyvinyl chloride plastisol<br>Poly-n-Butyl acrylate<br>Silicone/Acrylate blends<br>Aliphatic Polyurethanes | Mylar<br>Tedlar<br>Aluminum foil | As required |
| **Substrate Design** | | | |
| Fiberboard<br>Flakeboard<br>Mild steel<br>Glass reinforced concrete | (same as above) | Korad 201-R<br>Tedlar 100 BG-30 UT | |

Recent efforts have emphasized the identification and development of potting compounds. Pottants are materials which provide a number of functions, but primarily serve as a buffer between the cell and the surrounding environment. The pottant must provide a mechanical or impact barrier around the cell to prevent breakage, must provide a barrier to water which would degrade the electrical output, must serve as a barrier to conditions that cause corrosion of the cell metallization and interconnect structure, and must serve as an optical coupling medium to provide maximum light transmission to the cell surface and optimize power output. Pottants must obviously have very high transparency, with the exception of superstrate bonded designs in which cells are electrostatically bonded to the transparent superstrate and have no pottant over the front surface.

This report presents the results of a cost analysis performed for each of the candidate potting compounds of current interest and for each of the two encapsulation techniques being considered for large scale module manufacture. Factors included for consideration in the analyses were raw material cost, capital investment, equipment depreciation, labor, utilities, return on investment, etc. Each costing exercise is presented with a flow chart of the anticipated production method, itemized pricing of each step (appendixed) and a final summary sheet showing the projected cost of the compound or process in question.

# III. MANUFACTURING COST ESTIMATES

## A. EVA, SHEET, CLEAR

After an extensive investigation of transparent elastomers, ethylene/vinyl acetate (EVA) was selected from a class of low-cost polymers as being a likely candidate potting compound for use in the fabrication of solar cell arrays. Its selection was based on resin cost (approximately $0.59 per pound) and an appropriate combination of high optical transparency and easy processing conditions. This polymer also showed the most promising properties for immediate use with a small amount of modification, but without extensive development efforts.

EVA is available from the manufacturer (Elvax 150 - DuPont) as free flowing pellets. In order to convert the polymer to a form useful for the encapsulation of solar modules, two operations must be performed; compounding and extrusion. In the compounding stage, other chemicals are added to the polymer to improve its weathering resistance, improve its thermal stability and to enable it to be cured to transparent creep resistant rubber. In the extrusion stage, the material is converted to sheet form from which it may be conveniently wound on a core and stored in roll form. Additionally, the sheet form is desirable for encapsulation using the vacuum lamination technique, described later in this report. In actuality, the compounding and extrusion stages are conducted simultaneously. The process of intimate mixing and sheet formation is done at the same time in the extruder.

The steps envisioned in the large scale production of compounded EVA sheet are shown on the production flow chart on page number 3-4. The steps consist of (a) materials receipt and storage, (b) weighing and blending (steps 1, 12, 14) to yield "hopper feed" which is then fed to the (c) extruder from which the sheet is prepared (step 4, 5). The fully compounded sheet is then wound onto cores for shipping (steps 7,16). To conserve raw materials, the rough edges of the extruded sheet are cut off and fed into a granulator (step 8) for recycling into the feed hopper.

Each step of this production process has been costed out to yield what is hoped to be a realistic cost in terms of 1979 dollars. Factors used in the calculations included raw materials, direct and indirect labor, freight, insurance, depreciation and capital equipment. The estimates are tabulated on the summary, page 3-3. Based on these calculations, the cost for transparent EVA sheet on a production basis is found to be $0.095 per square foot in 20 mil thickness.

The reader is referred to Appendix I for the assumptions and details of these calculations.

## SUMMARY

### MANUFACTURING COST ESTIMATE
### EVA SHEET, CLEAR

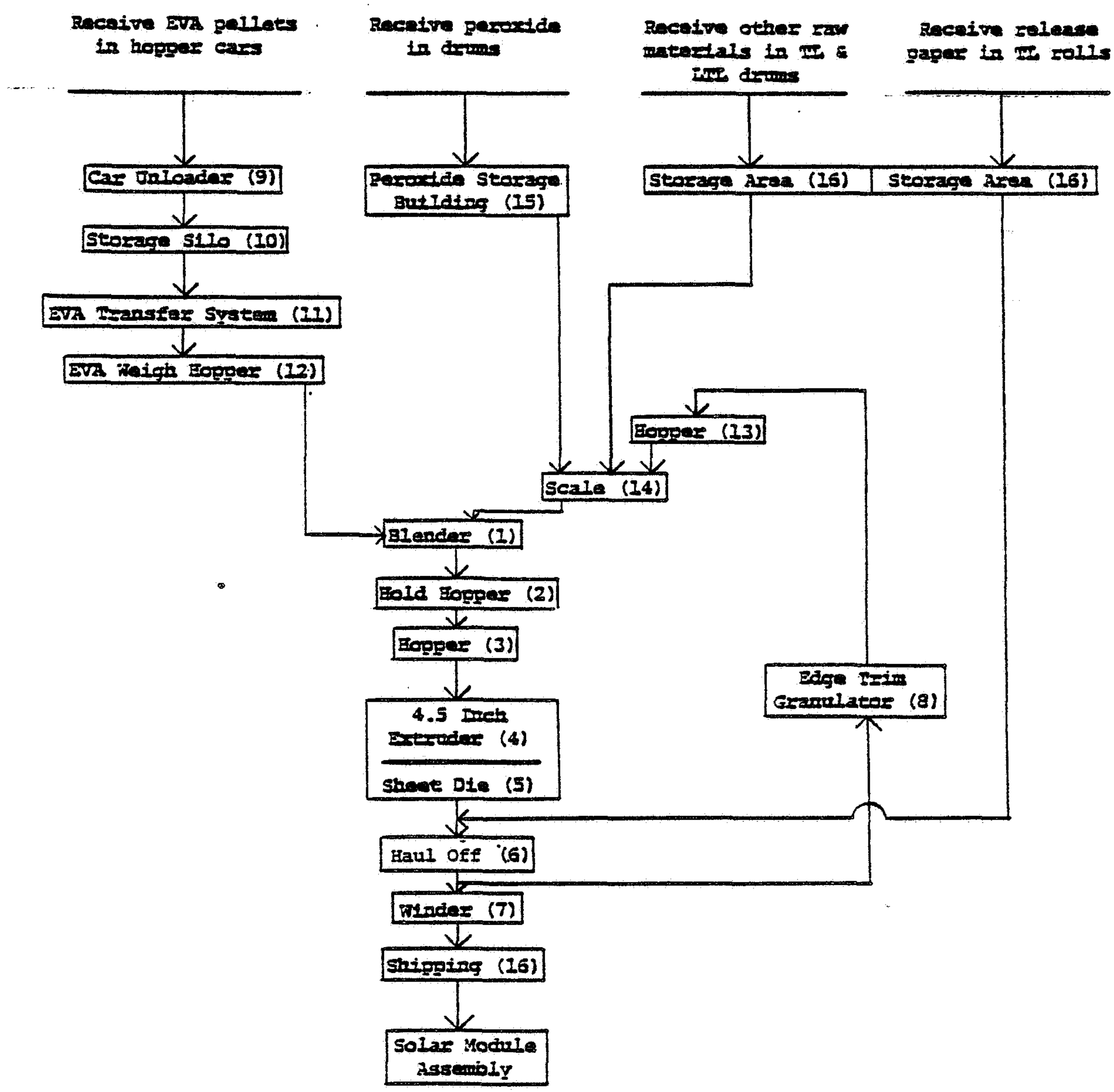
(Formula A9918)
Sheet Thickness; 20 mils

| | Annual, $ | 85.284 million $ft^2/yr$<br>$ per sq. ft. | 8,568,000 lbs/yr<br>$ per lb | % |
|---|---|---|---|---|
| Operating costs | | | | |
| Variable | | | | |
| Raw materials | 6,227,800 | 0.0730 | 0.7269 | 80.01 |
| Direct Labor | 276,300 | 0.0032 | 0.0032 | 3.55 |
| Fringes on direct labor, 30% | 82,900 | 0.0010 | 0.0097 | 1.07 |
| Utilities | 202,100 | 0.0024 | 0.0236 | 2.60 |
| Freight in and out | 21,600 | 0.0003 | 0.0025 | 0.28 |
| Packaging | --- | --- | --- | --- |
| Maintenance supplies, 1% of 1.295,900 | 13,000 | 0.0002 | 0.0015 | 0.17 |
| Maintenance labor, 1% of 1,295,900 | 13,000 | 0.0002 | 0.0015 | 0.17 |
| Other supplies | 521,300 | 0.0061 | 0.0608 | 6.70 |
| By products-credits | --- | --- | --- | --- |
| | 7,358,000 | 0.0863 | 0.8588 | 94.54 |
| Fixed | | | | |
| Indirect labor, 0.6 x direct labor | 165,800 | 0.0019 | 0.0194 | 2.13 |
| Fringes on indirect labor, 30% | 49,700 | 0.0006 | 0.0058 | 0.64 |
| Depreciation | 144,900 | 0.0017 | 0.0169 | 1.86 |
| Insurance and taxes, 3% of 1,295,900 | 38,900 | 0.0005 | 0.0045 | 0.50 |
| Maintenance supplies, 1% of 1,295,900 | 13,000 | 0.0002 | 0.0015 | 0.17 |
| Maintenance labor, 1% of 1,295,900 | 13,000 | 0.0002 | 0.0015 | 0.17 |
| | 425,300 | 0.0050 | 0.0496 | 5.46 |
| Manufacturing cost | 7,783,300 | 0.0913 | 0.9084 | 100.00 |
| Working capital 485,800 | | | | |
| ROI before tax at 20% of 1,295,900 + 485,800 | 356,300 | 0.0042 | 0.0416 | |
| Manufacturing cost + ROI | 8,139,600 | $\boxed{0.0954}$ | 0.9500 | |

| Capital Equipment and Buildings | Life | Annual Depreciation |
|---|---|---|
| 862,900 | 7 yrs | $ 123,271 |
| 433,000 | 20 yrs | 21,650 |
| 1,295,900 | | 144,921 |
| | | $ 144,900 |

# PRODUCTION FLOW CHART
# EVA, CLEAR

(Formula A9918)



## B. EVA, SHEET, PIGMENTED

The pigmented EVA formulation is based on the same resin and production principles as the clear equivalent described in Section III. A. Although the chemistry of the stabilization system is somewhat different, the primary difference is the inclusion of pigments to give the sheet a white color. The reason for this is that a white background behind the cells serves to reflect the light back towards the surface of the module causing internal reflection. The result of this is that more light energy is utilized and the power output of the module is increased.

Although the compounding and extrusion steps are essentially the same as for the clear material, an additional step must be added in which the pigment is dispersed. Simple addition of the pigments to the blender to give a hopper feed are unsuccessful. The extruded sheet shows signs of streaking, undispersed clumps of powder, and other signs of improper blending. The diffulties are only overcome by predispersing the pigments in a small amount of resin to give a "masterbatch" of compounded pellets that may then be added to the hopper feed. This preparation of masterbatch requires a separate compounding step on the side before the product is fed into the main blender that supplies the "hopper feed" for the primary extrusion operation.

The steps involved in the large scale production of pigmented EVA sheet are outlined on the production flow chart on page number 3-8. The primary compounding steps can be seen to be the same as for the clear compound; (a) raw material storage (steps 16, 17, 25, 26), and (b) weighing and blending (8, 23) to give the hopper feed (9, 10). The sheet extrusion and roll winding with release paper (11, 12, 13, 14) complete the product. The preparation of the masterbatch can be seen as a separate line of items on the right hand side of the flow chart. In this procedure, a small amount of EVA pellets are mixed with the pigment and stabilizer compounds by blending (steps 22, 24, 1, 2, 3) and the high shear compounding performed by a twin screw extruder (4, 5). The output of the extruder then runs into a pelletizer (6) that produces masterbatch pellets that are then transferred to the main blender (8) for the preparation of hopper feed.

Cost calculations included a slight increase in the cost of raw materials and processing as well as the usual labor, freight, insurance, depreciation, etc.

The estimates are tabulated on the summary, page 3-7. Based on these calculations, the cost for pigmented EVA sheet on a large scale production basis is found to be $0.10 per square foot.

The reader is referred to Appendix II for a detailed presentation of the assumptions and calculations used in this exercise.

## SUMMARY

### MANUFACTURING COST ESTIMATE
### EVA SHEET, PIGMENTED

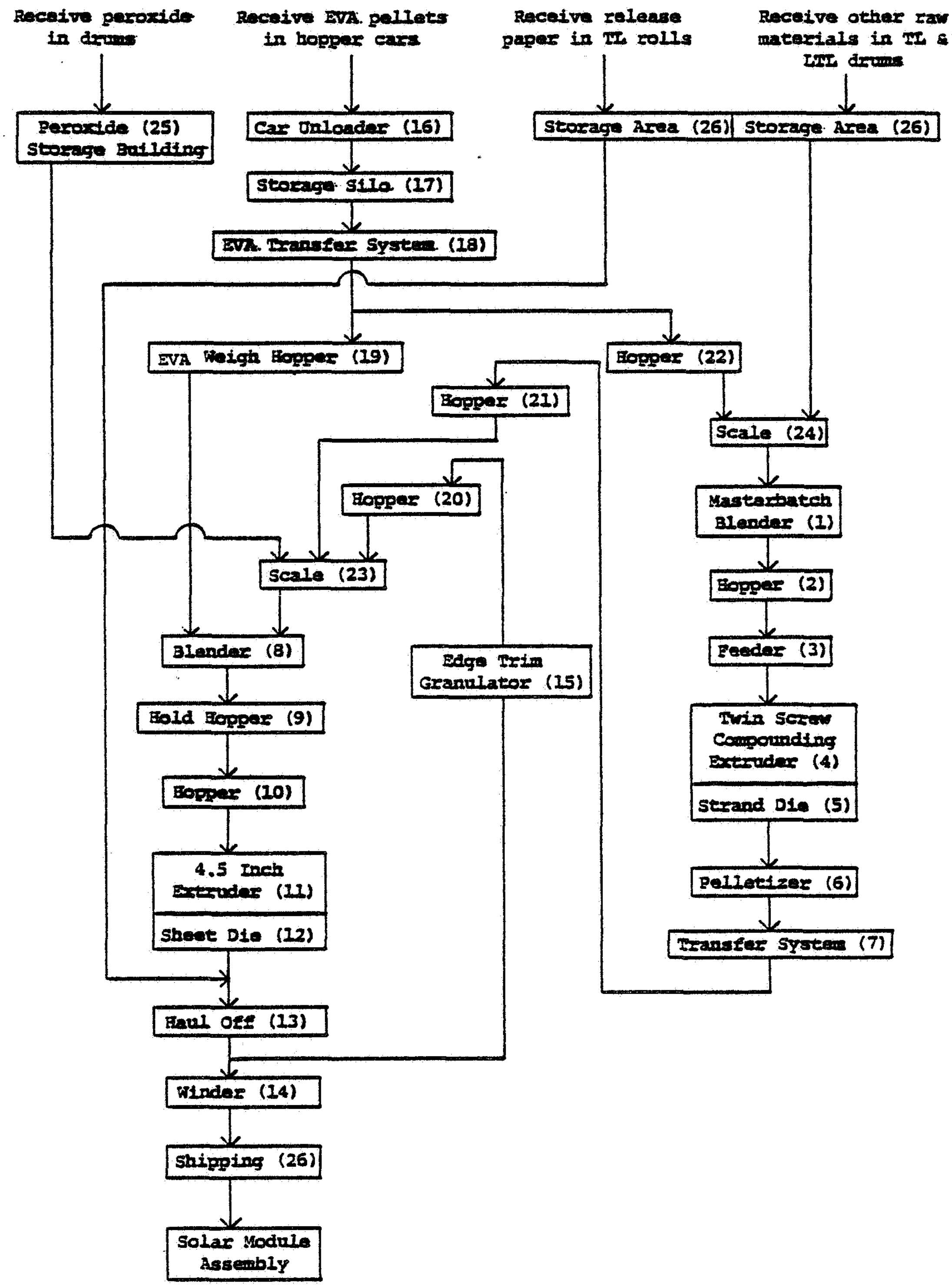
(Formula A9930)
Sheet thickness; 20 mils

| | Annual $ | 83.980 million $ft^2$/yr<br>$ per sq. ft. | 8,568,000 lbs/yr<br>$ per lb | % |
|---|---|---|---|---|
| Operating Costs | | | | |
| Variable | | | | |
| Raw materials | 6,020,900 | 0.0717 | 0.7027 | 75.86 |
| Direct labor | 377,200 | 0.0045 | 0.0440 | 4.75 |
| Fringes on direct labor, 30% | 113,200 | 0.0013 | 0.0132 | 1.43 |
| Utilities | 240,900 | 0.0029 | 0.0281 | 3.04 |
| Freight in and out | 21,300 | 0.0003 | 0.0025 | 0.27 |
| Packaging | --- | --- | --- | --- |
| Maintenance labor, 1% of 1,976,800 | 19,800 | 0.0002 | 0.0023 | 0.25 |
| Maintenance labor, 1% of 1,976,800 | 19,800 | 0.0002 | 0.0023 | 0.25 |
| Other supplies | 511,100 | 0.0061 | 0.0597 | 6.44 |
| By products-credits | --- | --- | --- | --- |
| | 7,324,200 | 0.0872 | 0.8548 | 92.28 |
| Fixed | | | | |
| Indirect labor, 0.6 x direct labor | 226,300 | 0.0027 | 0.0264 | 2.85 |
| Fringes on indirect labor, 30% | 67,900 | 0.0008 | 0.0079 | 0.86 |
| Depreciation | 219,400 | 0.0026 | 0.0256 | 2.76 |
| Insurance and taxes, 3% of 1,976,800 | 59,300 | 0.0007 | 0.0069 | 0.75 |
| Maintenance supplies, 1% of 1,976,800 | 19,800 | 0.0002 | 0.0023 | 0.25 |
| Maintenance labor, 1% of 1,976,800 | 19,800 | 0.0002 | 0.0023 | 0.25 |
| | 612,500 | 0.0073 | 0.0715 | 7.72 |
| Manufacturing Cost | 7,936,700 | 0.0945 | 0.9263 | 100.00 |
| Working capital 481,000 | | | | |
| ROI before tax at 20% of 1,976,800 + 481,000 | 491,600 | 0.0059 | 0.0574 | |
| Manufacturing Cost + ROI | 8,428,300 | 0.1004 | 0.9837 | |

| Capital equipment and buildings | Life | Annual Depreciation |
|---|---|---|
| 1,297,800 | 7 yrs | $ 185,400 |
| 679,000 | 20 yrs | 33,950 |
| 1,976,800 | | 219,350 |
| | | $ 219,400 |

PRODUCTION FLOW CHART
EVA, WHITE

(Formula A9930)



## C. EPDM, SHEET, CLEAR

Preliminary investigations of pottants other than EVA have been conducted over the past year. These compounds are regarded as "second choice" materials to provide alternative encapsulants in the event that EVA is less suitable for a particular design or process.

The criteria for these alternate pottants is essentially the same as for EVA; high transparency, processability, weatherability or the ability to be made weatherable and acceptable cost.

The first alternate system to be investigated is based on EPDM, ethylene-propylene-diene rubber. Samples of this resin with appropriate melt flow values were received from the manufacturer (Nordel 1320-DuPont) and compounded to give trial formulations. These formulations were then prepared on laboratory equipment that simulated large scale production in order to examine the processing conditions.

This polymer, being a rubber, is more difficult to handle than the EVA copolymers. The melt viscosity is higher, the extrusion speed lower and higher temperatures are required for extrusion. "Scorch" (premature crosslinking) also must be taken into account at the higher extrusion temperatures required (225$^{o}$F).

Although the extrusion temperatures are hotter for EPDM than EVA, no problems in formulating a successful cure and stabilization system for the higher temperature are anticipated.

The different physical properties of EPDM necessitate a different production process than that used for EVA. The resin is supplied in "bulk" form as opposed to flowing pellets and consequently must be compounded with the stabilizers and curing agents in a batch type blender, known as a Banbury mixer (see production flow chart, pp. 3-12 ), step 1. The bulk compound resulting from this mixing operation is then transferred to a two-roll mill where it is further blended to insure homogeneity (step 2) and prepare crude sheet. This sheet must be further processed to give a product of uniform width and thickness which may then be used for module fabrication. This step is accomplished with the use of a calender mill (step 3) from which the pottant is then wound onto rolls with release paper and prepared for shipment (steps 4, 7).

The manufacturing cost estimates for this process are shown on page 3-11 and include such factors as raw material costs, labor, freight, insurance, depreciation, etc. Based on these calculations, the cost for 20 mil thick encapsulation grade EPDM is found to be approximately $0.11 per square foot.

The reader is referred to Appendix III for details and assumptions used in the preparation of this cost estimate.

## SUMMARY

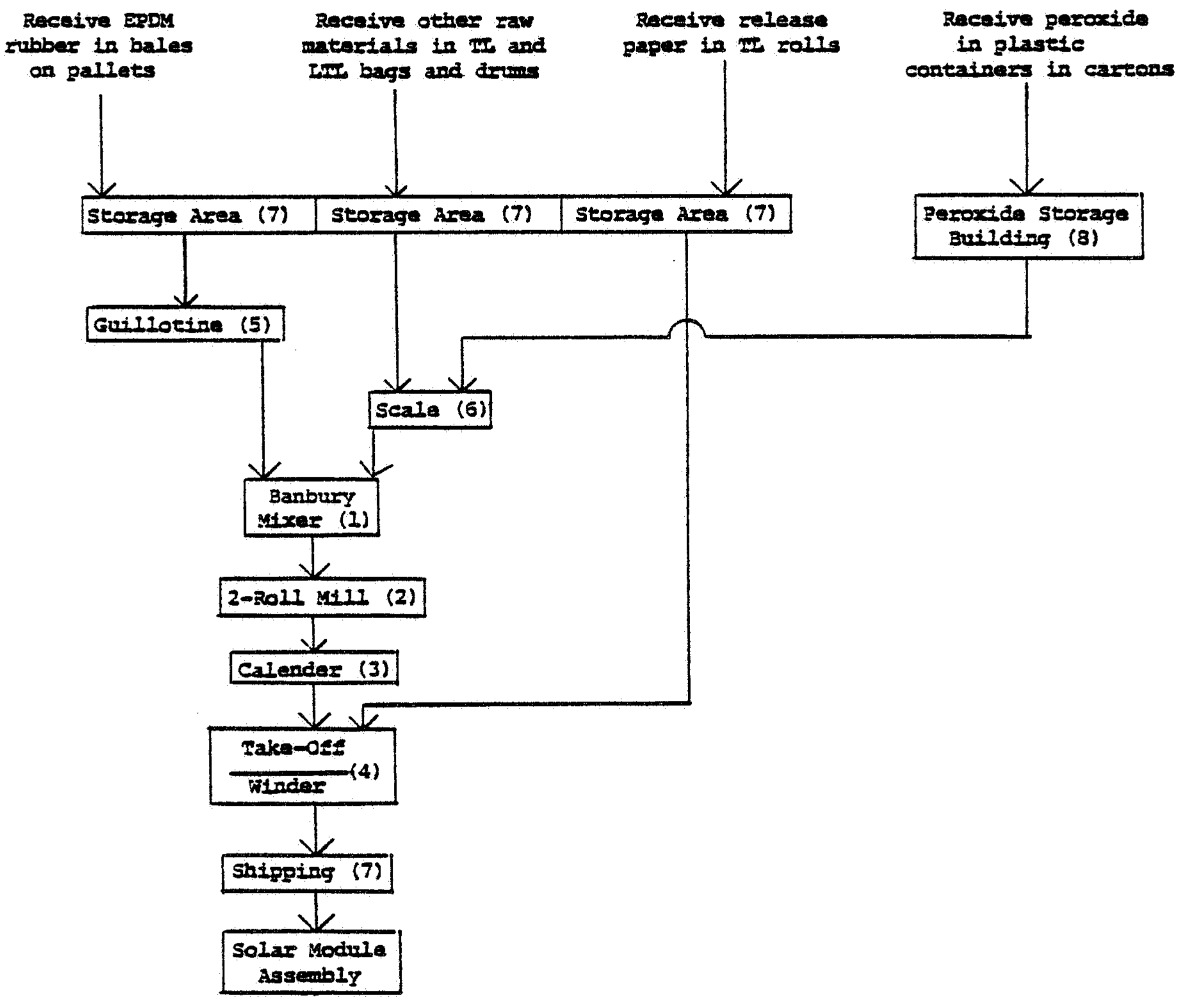
### MANUFACTURING COST ESTIMATE
### EPDM SHEET

(Formula A8945A)
Based on sheet 20 mil thick

| | Annual $ | $101.154 \times 10^6$ $ft^2/yr$ — $ per sq. ft. | 9,220,800 lbs/yr — $ per lb | % |
|---|---|---|---|---|
| **Operating Costs** | | | | |
| Variable | | | | |
| Raw materials | 7,378,900 | 0.0729 | 0.8002 | 76.65 |
| Direct labor | 355,300 | 0.0035 | 0.0385 | 3.69 |
| Fringes on direct labor, 30% | 106,600 | 0.0011 | 0.0116 | 1.11 |
| Utilities | 231,100 | 0.0023 | 0.0251 | 2.40 |
| Freight in and out | 294,100 | 0.0029 | 0.0319 | 3.05 |
| Packaging | --- | --- | --- | --- |
| Maintenance supplies, 1% of 1,923,700 | 19,200 | 0.0002 | 0.0021 | 0.20 |
| Maintenance labor, 1% of 1,923,700 | 19,200 | 0.0002 | 0.0021 | 0.20 |
| Other supplies (mostly release paper) | 618,200 | 0.0061 | 0.0670 | 6.42 |
| By products-credits | --- | --- | --- | --- |
| | 9,022,600 | 0.0892 | 0.9785 | 93.72 |
| Fixed | | | | |
| Indirect labor, 0.6 x direct labor | 213,200 | 0.0021 | 0.0231 | 2.21 |
| Fringes on indirect labor, 30% | 64,000 | 0.0006 | 0.0069 | 0.66 |
| Depreciation | 231,200 | 0.0023 | 0.0251 | 2.40 |
| Insurance and taxes, 3% of 1,923,700 | 57,700 | 0.0006 | 0.0063 | 0.60 |
| Maintenance supplies, 1% of 1,923,700 | 19,200 | 0.0002 | 0.0021 | 0.20 |
| Maintenance labor, 1% of 1,923,700 | 19,200 | 0.0002 | 0.0021 | 0.20 |
| | 604,500 | 0.0060 | 0.0656 | 6.28 |
| Manufacturing Cost | 9,627,100 | 0.0952 | 1.0441 | 100.00 |
| Working capital $626,500 | | | | |
| ROI before tax at 20% of 1,923,700 + 626,500 | 502,000 | 0.0050 | 0.0544 | |
| Manufacturing Cost + ROI | 10,129,100 | $\boxed{0.1002}$ | 1.0985 | |

| Capital equipment and buildings | Life | Annual Depreciation |
|---|---|---|
| 1,453,700 | 7 yrs | $ 207,671 |
| 470,000 | 20 yrs | 23,500 |
| 1,923,700 | | 231,171 |
| | | $ 231,200 |

PRODUCTION FLOW CHART
EPDM SHEET



D. ALIPHATIC URETHANE, SYRUP, CLEAR

The pottants developed and investigated to date have emphasized production in sheet form and consequently a fabrication method based on sheet lamination. Although the vacuum bag lamination process has been found to be very successful on experimental modules prepared to date, other methods of fabrication may be desirable to provide manufacturers with alternative production methods.

Liquid casting systems have been used in the past by the solar module industry with considerable success. The disadvantage with these systems is that they almost invariably use high cost silicone resin that is no longer acceptable under the JPL cost goals. Alternative casting materials were surveyed and a few identified as being potentially good candidates. Although not widely used, castable urethanes have been employed as solar module pottants. The major problem with the use of these compounds has been weathering resistance. This problem may possibly be overcome through the use of aliphatic urethane compounds (as opposed to aromatic) with additional protection supplied by a suitable outer cover material.

To date, our surveys have identified only one castable 100% solids aliphatic urethane system. This is available from H. J. Quinn & Co., Malden, Mass. The isocyanate prepolymer is designated Q-621 and is a transparent liquid of 3,400 centipoise viscosity and an equivalent weight of 520 - 540. It may be cured with a variety of diols. Quinn recommends their polyether diol designated Q-5829 or Q-626. After mixing the two part system, the pot life is approximately 3 hours at 70$^{\circ}$F. Cure conditions are 2 hours at 200$^{\circ}$F or about 6 hours at 120$^{\circ}$F. The cure rate is adjustable and depends on the quantity of catalyst used. The cost of the mixed system is estimated to be in the order of $1.30 per pound.

Test modules have been prepared from this system at Springborn Laboratories. The urethane is not found to be any more difficult to handle than any other liquid casting system.

The fabrication methods used with this type of pottant are very simple and the active "curable" compound is prepared by conventional mixing equipment immediately before use. The basic steps are outlined on the production flow chart (pp. 3-16). The two components are received by tankwagon and stored in appropriate tank facilities (steps 1, 2, 3, 4). When the production line is started up, the liquid components are run through thermostated deaeration reservoirs (steps 7, 8, 9, 10) and then mixed in correct proportions by metering pumps (steps 11, 12). The final degassed and mixed compound is dispensed directly to the solar cell module assembly from the mixer/dispenser head (step 13). Cure of the assembly then proceeds at room temperature, or may be accelerated by heat.

The calculated costs for this process are summarized on page 3-15 and are based on raw material costs, direct and indirect labor, capital equipment, depreciation, etc. Based on these assumptions, the cost of the aliphatic polyurethane system is found to be approximately $0.18 per square foot in 20 mil thicknesses.

The reader is referred to Appendix IV for the details and calculations used in the preparation of this estimate.

## SUMMARY

### MANUFACTURING COST ESTIMATE
### ALIPHATIC POLYURETHANE

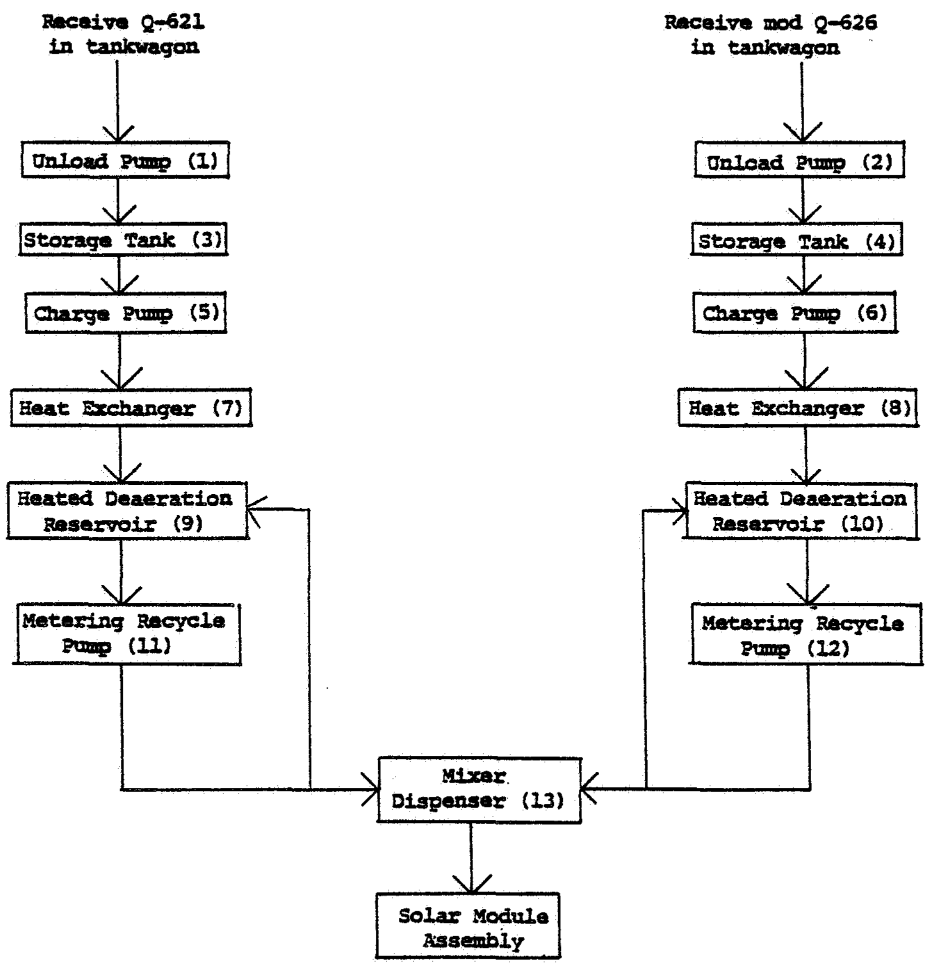
(Formulation Q621/Q626)
Based on sheet thickness of 20 mils

| | Annual $ | 85.00 million $ft^2$/yr<br>$ per sq. ft. | 9,109,300 lbs/yr<br>$ per lb | % |
|---|---|---|---|---|
| Operating Costs | | | | |
| Variable | | | | |
| Raw materials | 14,448,900 | 0.1700 | 1.5862 | 98.60 |
| Direct labor | 53,300 | 0.0006 | 0.0059 | 0.36 |
| Fringes on direct labor, 30% | 16,000 | 0.0002 | 0.0018 | 0.11 |
| Utilities | 11,900 | 0.0001 | 0.0013 | 0.08 |
| Freight in and out | --- | --- | --- | --- |
| Packaging | --- | --- | --- | --- |
| Maintenance supplies, 1% of 301,600 | 3,000 | <0.0001 | 0.0003 | 0.02 |
| Maintenance labor, 1% of 301,600 | 3,000 | <0.0001 | 0.0003 | 0.02 |
| Other supplies, 2% of 14,448,900 | 289,000 | 0.0034 | 0.0317 | 1.94 |
| By products-credits | --- | --- | --- | --- |
| | 14,825,100 | 0.1744 | 1.6275 | 99.32 |
| Fixed | | | | |
| Indirect labor, 0.8 x direct labor | 42,600 | 0.0005 | 0.0047 | 0.29 |
| Fringes on indirect labor, 30% | 12,800 | 0.0002 | 0.0014 | 0.08 |
| Depreciation | 30,600 | 0.0004 | 0.0034 | 0.21 |
| Insurance and taxes, 3% of 301,600 | 9,100 | 0.0001 | 0.0010 | 0.06 |
| Maintenance supplies, 1% of 301,600 | 3,000 | <0.0001 | 0.0003 | 0.02 |
| Maintenance labor, 1% of 301,600 | 3,000 | <0.0001 | 0.0003 | 0.02 |
| | 101,100 | 0.0012 | 0.0111 | 0.68 |
| Manufacturing Cost | 14,926,200 | 0.1756 | 1.6386 | 100.00 |
| Working capital $961,800 | | | | |
| ROI before tax at 20% of 961,800 + 301,600 | 252,700 | 0.0030 | 0.0277 | |
| Manufacturing cost + ROI | 15,178,900 | $\boxed{0.1786}$ | 1.6663 | |

| Capital equipment and buildings | Life | Annual depreciation |
|---|---|---|
| 166,600 | 7 yrs | $ 23,800 |
| 135,000 | 20 yrs | 6,750 |
| 301,600 | | 30,550 |
| | | $ 30,600 |

PRODUCTION FLOW CHART
ALIPHATIC POLYURETHANE

(Formula Q621/Q626)



## E. PVC PLASTISOL, SYRUP, CLEAR

Plastisols are also liquid systems that may be cast into molds and subsequently cured to tough rubbery compounds. Unlike the two component urethanes that cure upon mixing (and consequently have limited pot life) the plastisols are prepared as single compounds and may be kept indefinitely. The cure is initiated by heating to an appropriate fusion temperature after the liquid has been cast into the desired mold. Plastisols are prepared by high speed mixing of PVC (polyvinyl chloride) resin powder with high viscosity liquids known as plasticizers. Other components are also usually added to provide heat stability upon molding, modify the viscosity, provide coloration, etc.

A special plastisol compound designed for solar module fabrication (formula A10585-1) has been prepared at Springborn Laboratories. Although this compound is still in the development stage, it serves to represent this approach to the formulation of castable solar cell pottants, and provides a guideline from which a cost estimate may be prepared.

As with the castable urethane, the preparation of the plastisol is a fairly simple process using pumps and mixers. The anticipated production method is depicted on the production flow chart, pp. 3-19. The raw materials are received and held in appropriate storage facilities (steps 1-6, 19) from which they are weighed and blended in a high speed mixer (15) equipped with a dearator to remove bubbles. The resulting plastisol compound may then be stored in a silo and pumped (18) to the module fabrication line whenever production is started. The fusion temperature and cure time are estimated to be in the order of 20 minutes at 140$^{\circ}$C. This system is advantageous in that it uses simple equipment, is not sensitive to moisture in storage as urethanes are and has an indefinitely long storage life in its completely mixed state.

The cost calculations were based on the Springborn Laboratories experimental material and included such factors as raw material costs, freight, direct and indirect labor, capital equipment, etc. Based on these calculations, the cost of the PVC plastisol potting system is estimated to be $0.10 per square foot in 20 mil thicknesses.

The reader is referred to Appendix V for the details and calculations used in the preparation of this estimate.

SUMMARY

MANUFACTURING COST ESTIMATE
PVC PLASTISOL

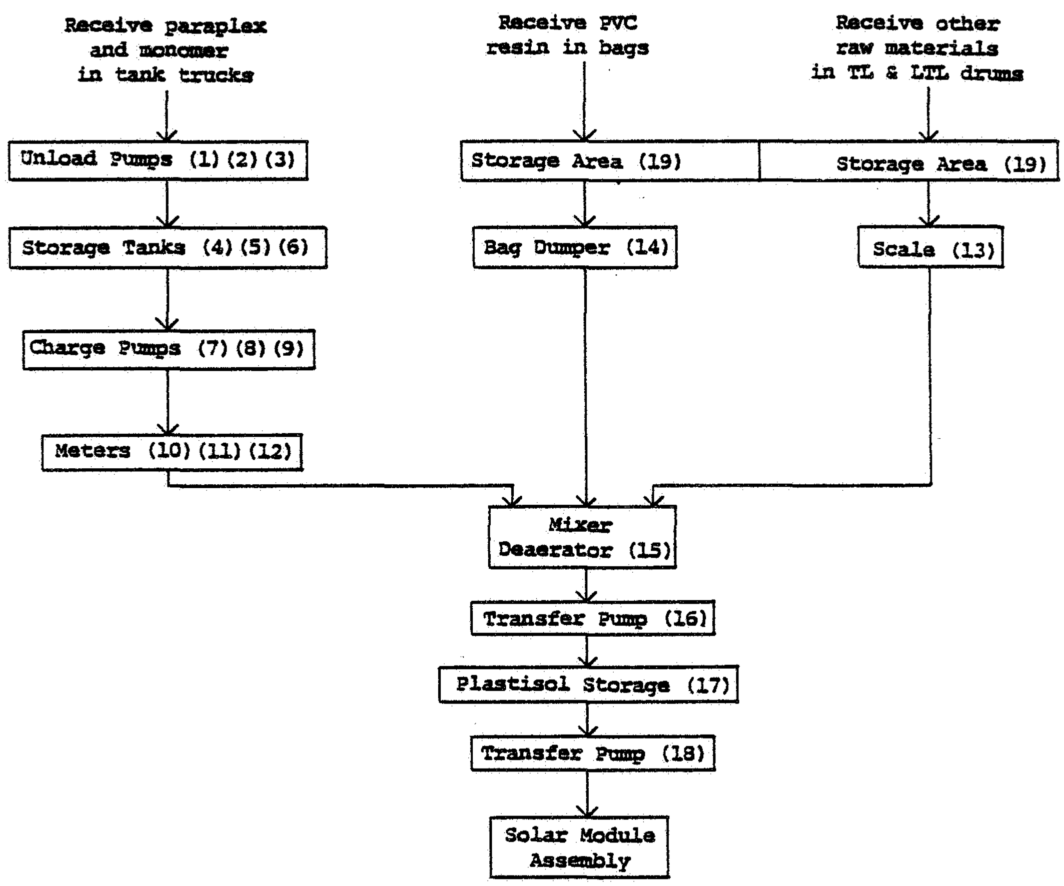
(Formulation A10585-1)
Based on sheet thickness of 20 mils

| | Annual $ | 86.265 million $ft^2$/yr<br>$ per sq. ft. | 10,855,600 lbs/yr<br>$ per lb | % |
|---|---|---|---|---|
| Operating Costs | | | | |
| Variable | | | | |
| Raw materials | 8,260,700 | 0.0958 | 0.7610 | 94.07 |
| Direct labor | 96,700 | 0.0011 | 0.0089 | 1.10 |
| Fringes on direct labor, 30% | 29,000 | 0.0003 | 0.0027 | 0.33 |
| Utilities | 14,600 | 0.0002 | 0.0013 | 0.17 |
| Freight in and out | --- | --- | --- | --- |
| Packaging | --- | --- | --- | --- |
| Maintenance supplies, 1% of 702,100 | 7,000 | 0.0001 | 0.0006 | 0.08 |
| Maintenance labor, 1% of 702,100 | 7,000 | 0.0001 | 0.0006 | 0.08 |
| Other supplies | 165,200 | 0.0019 | 0.0152 | 1.88 |
| By products-credits | --- | --- | --- | --- |
| | 8,580,200 | 0.0995 | 0.7904 | 97.70 |
| Fixed | | | | |
| Indirect labor, 0.8 x direct labor | 77,400 | 0.0009 | 0.0071 | 0.88 |
| Fringes on indirect labor, 30% | 23,200 | 0.0003 | 0.0021 | 0.26 |
| Depreciation | 66,000 | 0.0008 | 0.0061 | 0.75 |
| Insurance and taxes, 3% of 702,100 | 21,100 | 0.0002 | 0.0019 | 0.24 |
| Maintenance supplies, 1% of 702,100 | 7,000 | 0.0001 | 0.0006 | 0.08 |
| Maintenance labor, 1% of 702,100 | 7,000 | 0.0001 | 0.0006 | 0.08 |
| | 201,700 | 0.0023 | 0.0186 | 2.30 |
| Manufacturing Cost | 8,781,900 | 0.1018 | 0.8090 | 100.00 |
| Working Capital $581,600 | | | | |
| ROI before tax at 20% of 702,100 + 581,600 | 256,700 | 0.0030 | 0.0236 | |
| Manufacturing Cost + ROI | 9,038,600 | $\boxed{0.1048}$ | 0.8326 | |

| Capital equipment and buildings | Life | Annual Depreciation |
|---|---|---|
| 333,100 | 7 yrs | $ 47,586 |
| 369,000 | 20 yrs | 18,450 |
| 702,100 | | 66,036 |
| | | $ 66,000 |

PRODUCTION FLOW CHART
PVC PLASTISOL

(Formula A10585-1)



F. BUTYL ACRYLATE, SYRUP, CLEAR

Butyl acrylate is a water white low viscosity fluid commercially available at fairly low cost. It is sold as monomer of low molecular weight but has the ability to polymerize to a transparent rubber of excellent weathering stability. The rubber itself is difficult to work with but a more easily processable material may be prepared by dissolving some of the polymer in the monomer. This yields a high viscosity fluid or syrup that may then be used in the casting process in a manner similar to that used in the case of the plastisol and urethane systems. The syrup is injected into the mold cavity as with the other fluids and cured with the application of heat. Cure is initiated by the presence of a small amount of catalyst remaining in the syrup. The resulting pottant is tough, low in modulus, weatherable, resistant to temperature extremes and has high optical transmission.

The production process for polybutyl acrylate syrup involves kettle polymerization of the monomer with subsequent inhibition (to stop the reaction) and dilution with more monomer to give a monomer/polymer syrup of approximately 33% solids. The production process is somewhat more complicated than the procedures previously described for the other pottants. A detailed description of each process step outlined on the production flow chart (pp. 3-23) follows:

1. Receive n-butyl acrylate monomer in tank cars.
2. Pump n-butyl acrylate monomer from tank car to monomer storage tank.
3. Receive initiator and other additives by truck in drums and/or bags.
4. Receive inhibitor by truck in drums.
5. Transfer initiator to separate special storage building.
6. Transfer other additives and inhibitor to plant storage area.
7. Weigh initiator and other additives, charge to batch mixing tank.
8. Mix initiator and other additives in batch mixing tank.
9. Pump initiator/additives batch from batch mixing tank to feed tank.
10. Charge inhibitor to inhibitor feed tank.
11. Pump a continuous metered feed stream of monomer from the monomer storage tank to the stirred polymerization kettle.
12. Pump a corresponding continuous metered feed stream of initiator/additives from the feed tank to the stirred polymerization kettle.
13. Maintain the contents of the stirred polymerization kettle at a preselected polymerization temperature by jacket cooling.

14. Pending confirmatory experiments, assume average residence time of 12 hours at 80°C to reach 33% conversion in the stirred polymerization kettle.
15. Through an overflow port on the upper side wall of the stirred polymerization kettle, a continuous stream of 33% by weight polymer solution in monomer at 80°C flows from the kettle and passes through a water cooled heat exchanger where it is cooled to or below about 30°C.
16. After the polymer/monomer syrup stream leaves the heat exchanger, a metered ratio of inhibitor is continuously pumped into the syrup stream from the inhibitor feed tank and mixed into the syrup with an in-line mixer.
17. Following the inhibitor mixing step, the syrup flows into a syrup storage tank.
18. Syrup is pumped or otherwise shipped from the syrup storage tank to the solar cell encapsulation plant.

The costs calculated for this process are summarized on page 3-22 and are based on raw material costs, direct and indirect labor, capital equipment, etc. Based on these assumptions, the polybutyl acrylate pottant system is found to to have a cost in 20 mil thicknesses of approximately $0.06 per square foot.

The reader is referred to Appendix VI for the details of these calculations.

SUMMARY

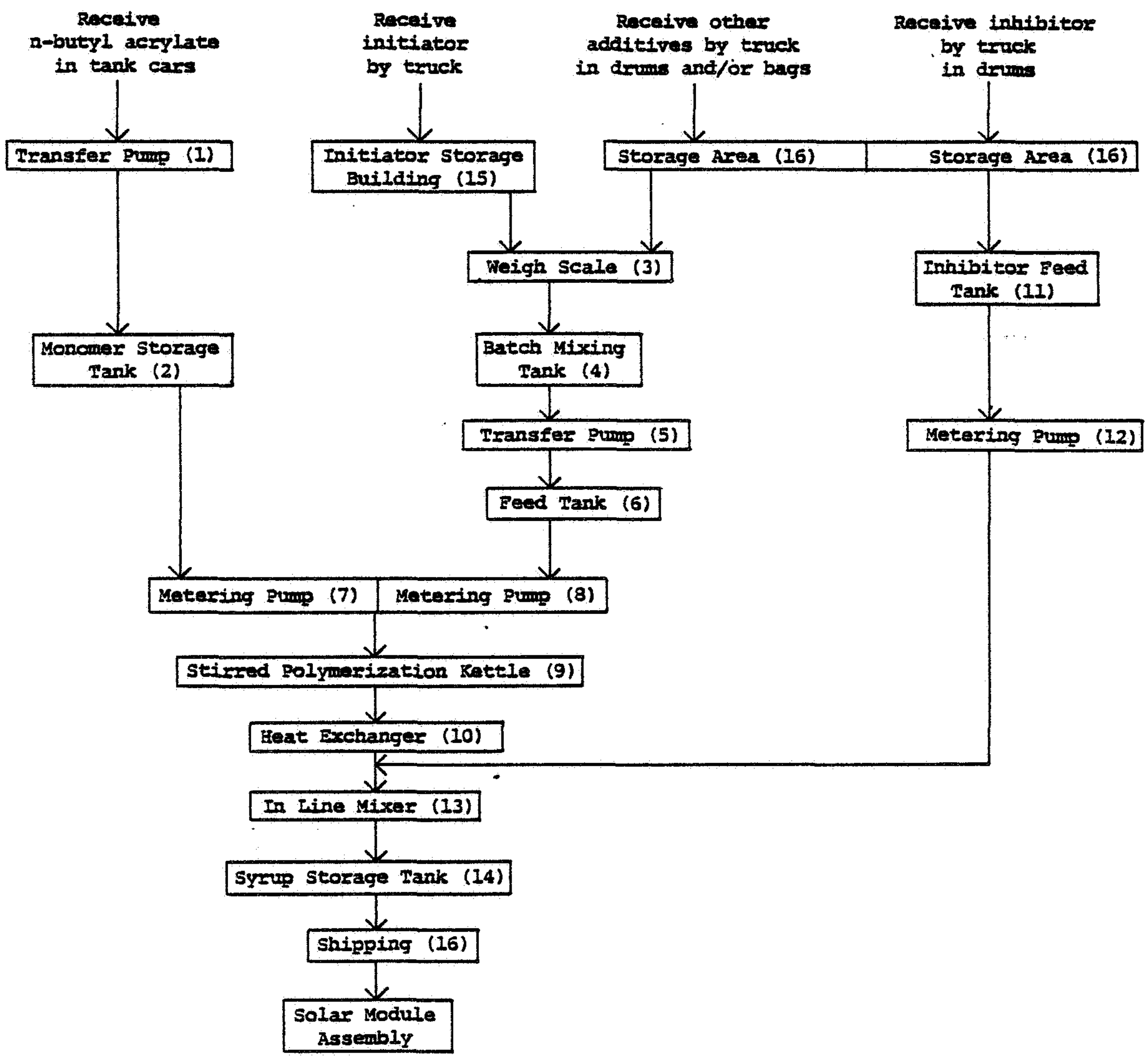
MANUFACTURING COST ESTIMATE
BUTYL ACRYLATE, SYRUP

Prepolymer syrup prepared from monomer
Based on 20 mil thickness

| | Annual $ | 68.00 million $ft^2/yr$ — $ per sq. ft. | 7,657,800 lbs/yr — $ per lb | % |
|---|---|---|---|---|
| Operating Costs | | | | |
| Variable | | | | |
| Raw materials | 3,648,800 | 0.0537 | 0.4777 | 88.74 |
| Direct labor | 127,200 | 0.0019 | 0.0167 | 3.09 |
| Fringes on direct labor, 30% | 38,200 | 0.0006 | 0.0050 | 0.93 |
| Utilities | 33,400 | 0.0005 | 0.0044 | 0.81 |
| Freight in and out | --- | --- | --- | --- |
| Packaging | --- | --- | --- | --- |
| Maintenance supplies, 1% of 392,000 | 3,900 | 0.0001 | 0.0005 | 0.09 |
| Maintenance labor, 1% of 392,000 | 3,900 | 0.0001 | 0.0005 | 0.09 |
| Other supplies, 2% of 3,648,800 | 73,000 | 0.0011 | 0.0096 | 1.78 |
| By products-credits | --- | --- | --- | --- |
| | 3,928,400 | 0.0578 | 0.5143 | 95.54 |
| Fixed | | | | |
| Indirect labor, 0.8 x direct labor | 101,800 | 0.0015 | 0.0133 | 2.48 |
| Fringes on indirect labor, 30% | 30,500 | 0.0004 | 0.0040 | 0.74 |
| Depreciation | 31,300 | 0.0005 | 0.0041 | 0.76 |
| Insurance and taxes, 3% of 392,000 | 11,800 | 0.0002 | 0.0015 | 0.29 |
| Maintenance supplies, 1% of 392,000 | 3,900 | 0.0001 | 0.0005 | 0.09 |
| Maintenance labor, 1% of 392,000 | 3,900 | 0.0001 | 0.0005 | 0.09 |
| | 183,200 | 0.0027 | 0.0240 | 4.46 |
| Manufacturing cost | 4,111,600 | 0.0605 | 0.5383 | 100.00 |
| Working capital 263,100 | | | | |
| ROI before tax at 20% of 392,000 + 263,100 | 131,000 | 0.0019 | 0.0172 | |
| Manufacturing cost + ROI | 4,242,600 | $\boxed{0.0624}$ | 0.5555 | |

| Capital equipment and buildings | Life | Annual Depreciation |
|---|---|---|
| $ 233,000 | 10 yrs | $ 23,300 |
| 159,000 | 20 yrs | 7,950 |
| $ 392,000 | | $ 31,250 |
| | | Use $ 31,300 |

PRODUCTION FLOW CHART
BUTYL ACRYLATE SYRUP



G. BUTYL ACRYLATE, SHEET, CLEAR

In addition to the butyl acrylate syrup system described in Section F. there is the possibility of preparing this polymer in a sheet form such that it may be used for the vacuum bag or other lamination type process. As with the EVA and EPDM resins (Sections A. and B.) the polybutyl acrylate resin is extruded through a sheet die and wound up on a core with a release paper interface. The wound sheet is then stored, shipped, and fed into the production line. Prior to this extrusion process, the resin must be prepared from monomer, however, as it is not commercially available as high molecular weight resin, which necessitates a somewhat complicated series of preparation steps. The whole sheet preparation process is outlined on the production flow chart (pp. 3-27) and the steps are described in detail as follows:

1. Receive n-butyl acrylate monomer in tank cars.
2. Pump n-butyl acrylate monomer from tank car to monomer storage tank.
3. Receive initiator and other additives by truck in drums and/or bags.
4. Receive Quilon release paper in truckload rolls.
5. Transfer initiator to separate special storage building.
6. Transfer other additives and release paper to plant storage area.
7. Weigh initiator and other additives in batch mixing tank.
8. Mix initiator and other additives in batch mixing tank.
9. Pump initiator/additives batch from batch mixing tank to feed tank.
10. Pump a continuous metered feed stream of monomer from the monomer storage tank to the stirred polymerization kettle.
11. Pump a corresponding continuous metered feed stream of initiator/additives from the feed tank to the stirred polymerization kettle.
12. Maintain the contents of the stirred polymerization kettle at a preselected polymerization temperature by jacket cooling.
13. Pending confirmatory experiments, assume average residence time of 12 hours at 80°C to reach 30-33% conversion in the stirred polymerization kettle.
14. Pump a continuous 30-33% polymerized stream from the bottom of the stirred polymerization kettle to the top of the second polymerization reactor (unstirred).
15. By means of zoned jacketing and zoned internal coils, gradually raise the temperature of the partially polymerized stream uniformly as it moves from the top to the bottom of the second polymerization reactor.

16. Pending confirmatory experiments, assume a temperature gradient of 80 to 150°C and residence time of 12 hours to reach 88% conversion in the second polymerization reactor.
17. By means of a melt pump, pump the melt continuously from the bottom of the second polymerication reactor through the melt preheater and into the top of the tower devolatilizer.
18. In the melt preheater, heat the melt from 150°C to, say, 200°C.
19. In the tower devolatilizer, under vacuum, strands of melt drop from the top by gravity to a pool of melt in the bottom, unpolymerized monomer and other volatiles vaporizing from the falling strands.
20. Pending confirmatory experiments, assume conversion reaches 94% by the time the melt reaches the tower devolatilizer; melt temperature is maintained at 200°C in the tower devolatilizer; 6% of charged ingredients is vaporized in the devolatilizer; 5% is condensed and collected as monomer and recycled to the monomer storage tank; and 1% of charged ingredients is either condensed and collected as oligomers and disposed of, or is not condensed and is therefore lost in the process.
21. By means of a melt pump, pump melt continuously from the bottom of the tower devolatilizer through the sheet die.
22. From the sheet die, continuously cast n-butyl acrylate polymer sheet on Quilon release paper.
23. Cool the cast sheet and trim it on the haul off equipment.
24. Recycle the sheet trim to a small screw extruder which feeds recycle trim melt into the polymerization melt stream between the first melt pump and melt preheater.
25. Wind the cast sheet with Quilon release paper interleaving in rolls.
26. Transfer rolls of cast n-butyl acrylate polymer on Quilon release paper to the roll storage area.
27. Ship rolls from the roll storage area to the solar cell encapsulation plant.

Each step of this production process has been costed out including factors such as raw material costs, direct and indirect labor, freight, insurance, capital equipment, etc., to yield a hopefully realistic cost estimate. Based on these assumptions and calculations, the cost of the polybutyl acrylate system in 20 mil thick sheet is found to be $0.08 per square foot.

The reader is referred to Appendix VII for details of the calculations used in preparation of this estimate.

SUMMARY

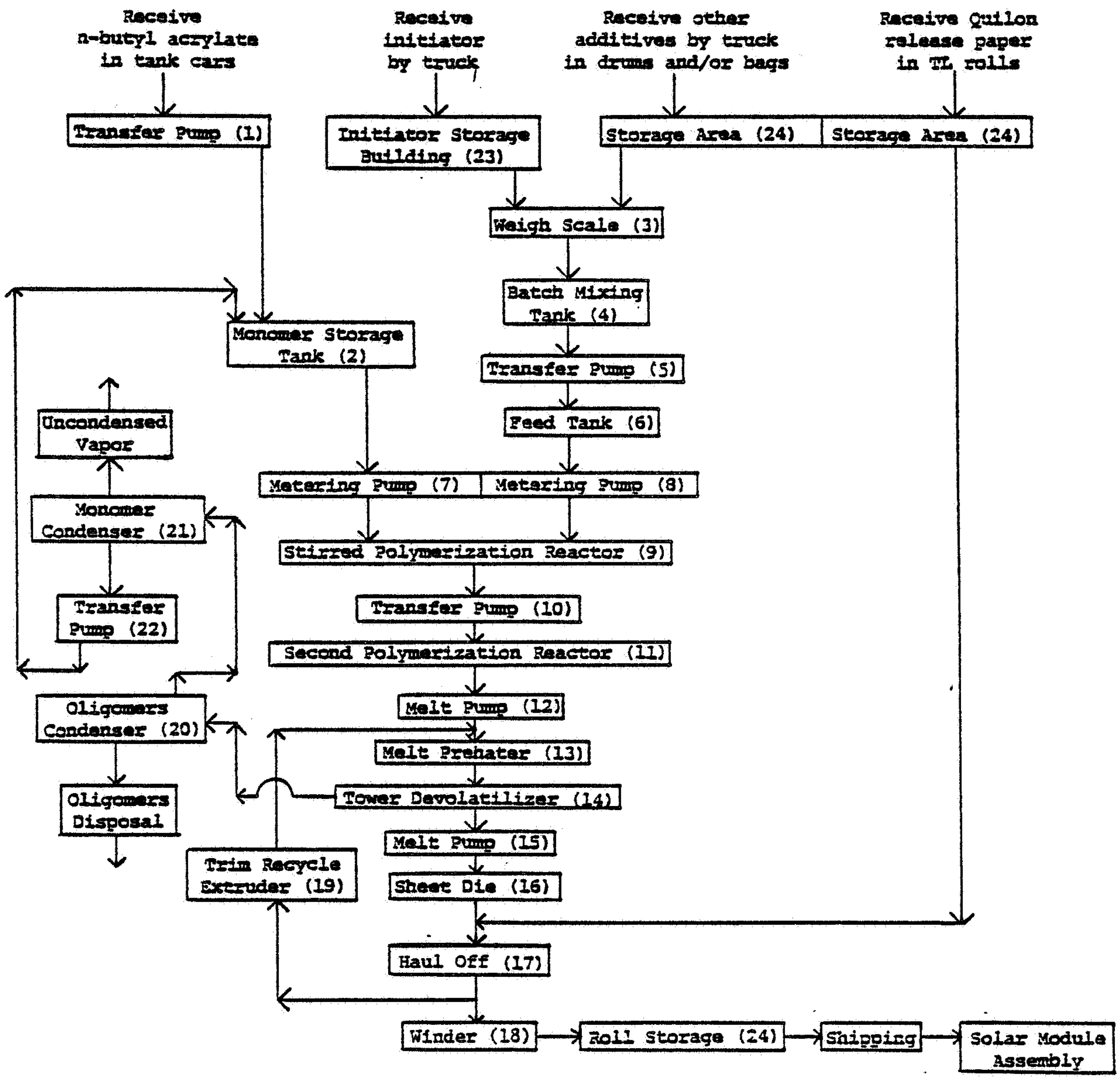
MANUFACTURING COST ESTIMATE
BUTYL ACRYLATE, SHEET

Polymer sheet from monomer
Based on 20 mils thickness

| | Annual $ | $ per sq. ft. (68.00 million $ft^2$/yr) | $ per lb (7,637,800 lbs/yr) | % |
|---|---|---|---|---|
| Operating Costs | | | | |
| Variable | | | | |
| Raw materials | 3,684,900 | 0.0542 | 0.4825 | 71.39 |
| Direct labor | 315,800 | 0.0046 | 0.0413 | 6.12 |
| Fringes on direct labor, 30% | 94,700 | 0.0014 | 0.0124 | 1.83 |
| Utilities | 73,000 | 0.0011 | 0.0096 | 1.41 |
| Freight in and out | 17,400 | 0.0003 | 0.0023 | 0.34 |
| Packaging | --- | --- | --- | --- |
| Maintenance supplies, 1% of 1,612,000 | 16,100 | 0.0002 | 0.0021 | 0.31 |
| Maintenance labor, 1% of 1,612,000 | 16,100 | 0.0002 | 0.0021 | 0.31 |
| Other supplies | 391,600 | 0.0058 | 0.0513 | 7.59 |
| By products credits | --- | --- | --- | --- |
| | 4,609,600 | 0.0678 | 0.6035 | 89.31 |
| Fixed | | | | |
| Indirect labor, 0.8 x direct labor | 252,600 | 0.0037 | 0.0331 | 4.89 |
| Fringes on indirect labor, 30% | 75,800 | 0.0011 | 0.0099 | 1.47 |
| Depreciation | 142,800 | 0.0021 | 0.0187 | 2.77 |
| Insurance and taxes, 3% of 1,612,000 | 48,400 | 0.0007 | 0.0063 | 0.94 |
| Maintenance supplies, 1% of 1,612,000 | 16,100 | 0.0002 | 0.0021 | 0.31 |
| Maintenance labor, 1% of 1,612,000 | 16,100 | 0.0002 | 0.0021 | 0.31 |
| | 551,800 | 0.0081 | 0.0722 | 10.69 |
| Manufacturing Cost | 5,161,400 | 0.0759 | 0.6758 | 100.00 |
| Working capital 305,800 | | | | |
| ROI before tax at 20% of 1,612,000 + 305,800 | 383,600 | 0.0056 | 0.0502 | |
| Manufacturing cost + ROI | 5,545,000 | $\boxed{0.0815}$ | 0.7260 | |

| Capital equipment and buildings | Life | Annual Depreciation |
|---|---|---|
| 1,243,000 | 10 yrs | 124,300 |
| 369,000 | 20 yrs | 18,450 |
| 1,612,000 | | 142,750 |
| | | $ 142,800 |

PRODUCTION FLOW CHART
BUTYL ACRYLATE SHEET



## IV. ENCAPSULATION PROCESS COST ESTIMATES

### A. SHEET LAMINATION TECHNIQUE

Many types of fabrication processes are conceivable for the large scale commercial production of solar modules. In the past, companies manufacturing solar modules have used predominantly a liquid casting method, based predominantly on the silicone elastomers. With the identification of solid materials as potentially useful pottants, a different fabrication scheme had to be considered. Springborn Laboratories has devised a vacuum bag lamination method from which fully encapsulated modules may be prepared from pottant supplied in sheet form. This process has been used with success on a laboratory scale for the production of modules as large as 11 inches by 15 inches containing eleven 90mm cells. The basic steps involved in this operation are as follows: assemble module components in sandwich form, place in a vacuum bag frame, evacuate the assembly, heat to fuse and cure pottant, cool, remove completed module[a]. This method is felt to be easily expandable to a large scale automated production facility with a high throughput capacity.

A manufacturing cost estimate was prepared from a flow chart (page 3-26) of the anticipated production steps to be used in this process. A detailed description of each production step follows:

<u>Construction, top (sun side) to bottom:</u>

1. Korad 212, film, 3 mils
2. EVA, clear, sheet, 18 mils
3. Solar cell, 23 mils
4. EVA, white sheet, 12 mils
5. Craneglass 230, non-woven glass fiber mat spacer, sheet, 5 mils
6. Super Dorlux hardboard, panels, 120 mils
7. Craneglass 230, non-woven glass fiber mat spacer, sheet, 5 mils
8. EVA, white, sheet, 12 mils

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(a) See: Investigation of Test Methods, Material Properties, and Processes for Solar Cell Encapsulants, Annual Report No. III, by Springborn Laboratories, Inc., Enfield, Conn. under JPL contract number 954527, June, 1979.

Operations

1. Receive Korad 212 film in rolls, 26 or 50 in. wide.
2. Receive clear EVA sheet in rolls, interleaved with release paper, 26 or 50 in. wide.
3. Receive solar cells, in prefabricated arrays, 24 in. x 48 in.
4. Receive white EVA sheet in rolls, interleaved with release paper, 26 or 50 in. wide.
5. Receive Craneglass 230 mat sheet in rolls, 24 or 48 in. wide.
6. Receive Super Dorlux panels, 24 in. x 48 in., stacked on pallets.
7. Transfer white EVA rolls to stack station 1.
8. Transfer Craneglass 230 rolls to stack station 2.
9. Transfer Super Dorlux panel pallets to stack station 3.
10. Transfer Craneglass 230 rolls to stack station 4.
11. Transfer white EVA rolls to stack station 5.
12. Transfer solar cell prefabricated arrays to stack station 6.
13. Transfer clear EVA rolls to stack station 7.
14. Transfer Korad 212 rolls to stack station 8.
15. Load white EVA roll on unwind stand at stack station 1 after removing previous roll core.
16. Load Craneglass 230 roll on unwind stand at stack station 2 after removing previous roll core.
17. Load pallet stack of Super Dorlux panels on unload stand at stack station 3 after removing previous emptied pallet.
18. Load Craneglass 230 roll on unwind stand at stack station 4 after removing previous roll core.
19. Load white EVA roll on unwind stand at stack station 5 after removing previous roll core.
20. Load solar cell prefabricated arrays on unload stand at stack station 6.
21. Load clear EVA roll on unwind stand at stack station 7 after removing previous roll core.
22. Load Korad 212 roll on unwind stand at stack station 8 after removing previous roll core.
23. Advance empty, clean, and open 26 in. x 50 in. molding frame to stack station 1 and index.

24. At stack station 1, automatically cut a 26 in. x 50 in. sheet of white EVA, with release paper interleaf attached, and automatically index and place it in the empty 26 in. x 50 in. molding frame, release paper side down in contact with frame back plate.
25. Advance molding frame to stack station 2 and index.
26. At stack station 2, automatically cut a 24 in. x 48 in. sheet of Craneglass 230, and automatically index and place it in the molding frame on top of the white EVA sheet, leaving 1-inch borders all around between edges of sheet and frame.
27. Advance molding frame to stack station 3 and index.
28. At stack station 3, automatically take one 24 in. x 48 in. Super Dorlux panel from the panel stack and automatically index and place it in the molding frame on top of the Craneglass 230 sheet, leaving 1-inch borders all around between edges of sheet and frame.
29. Advance molding frame to stack station 4 and index.
30. At stack station 4, automatically cut a 24 in. x 48 in. sheet of Craneglass 230, and automatically index and place it in the molding frame on top of the Super Dorlux panel, leaving 1-inch borders all around between edges of sheet and frame.
31. Advance molding frame to stack station 5 and index.
32. At stack station 5, automatically unroll and separate the white EVA from the interleaved release paper, rewind the release paper, cut a 26 in. x 50 in. sheet of white EVA, and automatically index and place it in the molding frame on top of the Craneglass 230 sheet.
33. Advance molding frame to stack station 6 and index.
34. At stack station 6, automatically pick up a prefabricated 24 in. x 48 in. solar cell array, and index and place it in the molding frame on top of the white EVA sheet, leaving 1-inch borders all around between edges of sheet and frame.
35. Advance molding frame to stack station 7 and index.
36. At stack station 7, automatically unwind and separate the clear EVA from the interleaved release paper, rewind the release paper, cut a 26 in. x 50 in. sheet of clear EVA, and automatically index and place it in the molding frame on top of the solar cell array.

37. Advance molding frame to stack station 8 and index.

38. At stack station 8, automatically cut a 26 in. x 50 in. sheet of Korad 212, and automatically index and place it in the molding frame on top of the clear EVA sheet.

39. Advance molding frame, close mold.

40. Advance molding frame to moving conveyor.

41. On moving conveyor, transport molding frame through vacuum application zone, programmed for vacuum application to both molding frame chambers, time in this zone 20 minutes.

42. On moving conveyor, transport molding frames through heating zone, between top and bottom heating platens, raise temperature of material in molding frame gradually to 120°C, time in this zone 20 minutes.

43. On moving conveyor, continue transport of molding frame through heating zone, between top and bottom heating platens, gradually release vacuum in upper molding frame chamber over 10 minutes, reach 140°C material temperature after about 6 minutes in this zone, hold 140°C for balance of 4 minutes in this zone.

44. On moving conveyor, continue transport of molding frame through heating zone, between top and bottom heating platens, maintain material temperature for 6 minutes more, continue vacuum application to lower molding frame chamber.

45. On moving conveyor, transport molding frame through cooling zone, between top and bottom cooling platens, continue vacuum application to lower molding frame chamber, time in this zone 10 minutes.

46. On moving conveyor, release vacuum to lower molding frame chamber, open molding frame, remove module assembly, place module on conveyor to inspection area, time in this zone 1 minute.

47. On moving conveyor, clean and inspect molding frame for next cycle, time in this zone 5 minutes.

48. Convey potted module assembly to inspection area.

49. Inspect and trim potted module assembly.

50. Transfer to packaging area.

51. Package potted module assembly.

52. Transfer to storage area.

53. Store potted module assembly.

54. Transfer to shipping area for shipment.

Based on these anticipated fabrication steps outlined in the production flow chart, a total process cost can be calculated. The Summary (page 3-33) gives the results of this costing exercise and includes such factors as direct and indirect labor, utilities, freight, insurance, maintenance, etc. The encapsulation process cost based on the vacuum bag or sheet lamination technique is found to be $6.93 per module of 2 foot by 4 foot dimensions, or a cost of $0.87 per square foot.

The reader is referred to Appendix VIII for detail and calculations used in the preparation of this process cost estimate.

SUMMARY

SOLAR CELL ENCAPSULATION PROCESS
SHEET LAMINATION TECHNIQUE

COST ESTIMATE

Cost based on:
Pottant: EVA
Design: Substrate
Size: 2 ft x 4 ft

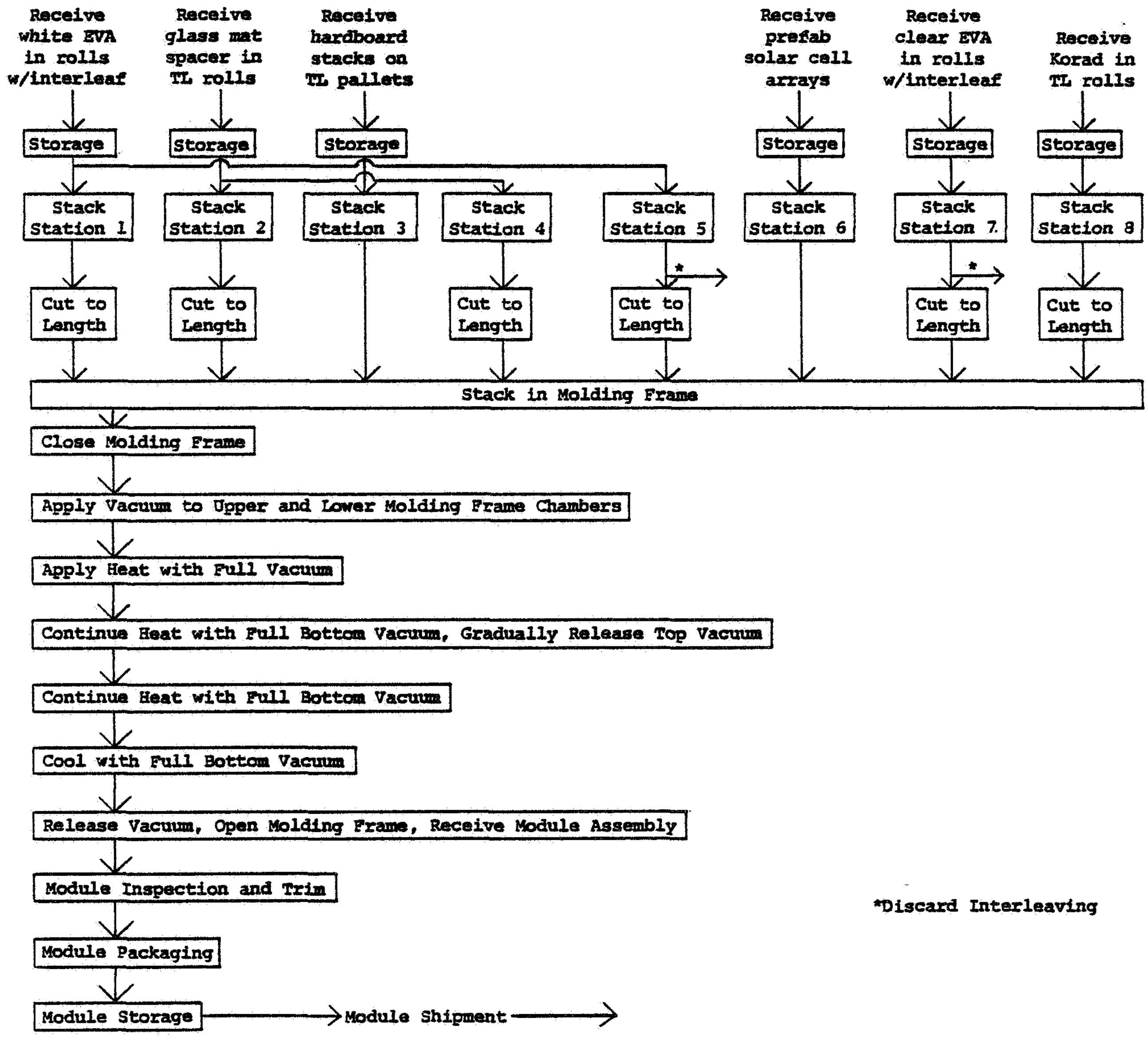
| | Annual $ | 6.25 million modules/yr $ per module | 50 million sq. ft./yr $ per sq. ft. | % |
|---|---|---|---|---|
| Operating Costs | | | | |
| Variable | | | | |
| Raw materials* | 21,531,900 | 3.4451 | 0.4306 | 59.14 |
| Direct Labor | 2,693,300 | 0.4309 | 0.0539 | 7.40 |
| Fringes on direct labor, 30% | 808,000 | 0.1293 | 0.0162 | 2.22 |
| Utilities | 1,679,000 | 0.2686 | 0.0336 | 4.61 |
| Freight in and out | 355,500 | 0.0569 | 0.0071 | 0.98 |
| Packaging | 125,000 | 0.0200 | 0.0025 | 0.34 |
| Maintenance supplies, 1% of 32,095,000 | 321,000 | 0.0514 | 0.0064 | 0.88 |
| Maintenance labor, 1% of 32,095,000 | 321,000 | 0.0514 | 0.0064 | 0.88 |
| Other supplies, 2% of 21,531,900 | 430,600 | 0.0689 | 0.0086 | 1.88 |
| By products credits | --- | --- | --- | --- |
| | 28,265,300 | 4.5224 | 0.5653 | 77.64 |
| Fixed | | | | |
| Indirect labor, 0.6 x direct labor | 1,616,000 | 0.2586 | 0.0323 | 4.44 |
| Fringes on indirect labor, 39% | 484,800 | 0.0776 | 0.0097 | 1.33 |
| Depreciation | 4,435,700 | 0.7097 | 0.0887 | 12.18 |
| Insurance and taxes, 3% of 32,095,000 | 962,900 | 0.1541 | 0.0193 | 2.64 |
| Maintenance supplies, 1% of 32,095,000 | 321,000 | 0.0514 | 0.0064 | 0.88 |
| Maintenance labor, 1% of 32,095,000 | 321,000 | 0.0514 | 0.0064 | 0.88 |
| | 8,141,400 | 1.3026 | 0.1628 | 22.36 |
| Manufacturing Cost* | 36,406,700 | 5.8251 | 0.7281 | 100.00 |
| Working capital* 2,666,300 | | | | |
| ROI before tax at 20% of 32,095,000 + 2,666,300 | 6,952,300 | 1.1124 | 0.1390 | |
| Manufacturing Cost + ROI* | 43,359,000* | 6.9374* | 0.8672* | |

| Capital equipment and buildings | Life | Annual Depreciation |
|---|---|---|
| $ 1,610,000 | 2 yrs | 805,000 |
| 22,685,000 | 7 yrs | 3,240,700 |
| 7,800,000 | 20 yrs | 390,000 |
| $ 32,095,000 | | 4,435,700 |

*Excludes Solar Cell Arrays

Cost based on:
Pottant: EVA
Design: Substrate
Size: 2 ft x 4 ft

PRODUCTION FLOW CHART
SOLAR CELL ENCAPSULATION
LAMINATION TECHNIQUE



## B. LIQUID CASTING TECHNIQUE

The liquid casting technique was the first method used for the encapsulation of solar modules on a small scale production basis. The reason for this is that the technique was relatively simple, the risk of damage to the cells was low and the pottant used (silicone) was highly transparent and weather stable. The disadvantage is that the silicones are too expensive for use in a national energy program despite their excellent performance. Other possible liquid casting compounds were investigated for use as long life encapsulation compounds. To date, only three have been selected by Springborn Laboratories as candidate encapsulants. They are aliphatic urethanes, polyvinyl chloride plastisol and polybutyl acrylate. These compounds must be properly formulated for outdoor use and only intermediate compounds have been developed to date. These compounds will provide manufacturers with an alternate method of fabrication that may be preferred to the lamination technique previously described. In use, it is anticipated that the liquid casting syrup will be injected into a sealed frame or enclosure containing the other solar module components and subsequently cured in place. The frame is split open after the cure and the completed module removed. A diagram of this equipment is shown in Figure 1, Page 3-41. In terms of a large scale production facility, a multi-step operation is necessary as is outlined on the production flow chart shown on page 3-40. A detailed description of each step follows:

Construction, top (sun side) to bottom:

1. Clear glass sheet, 0.100 in.
2. Plastisol casting liquid, 20 mils.
3. Vinyl spacer buttons, 20 mils.
4. Solar cell, 23 mils.
5. Craneglass 230, non woven glass fiber mat spacer, sheet, 5 mils.
6. Aluminum foil, 1 mil.

Operations

1. Receive and store aluminum foil in rolls, 26 in. or 50 in. wide.
2. Receive and store Craneglass 230 mat sheet in rolls, 24 in. or 48 in. wide.
3. Receive and store solar cells, in prefabricated arrays, 24 in. x 48 in.
4. Receive and store vinyl spacer button strip in rolls, 1 in. wide.

5. Receive and store glass sheet in stacks on pallets, precleaned, with lint-free interleaf to prevent scratching.
6. Receive plastisol, pumped from plastisol compounding plant (gentle laminar, non-turbulent pumping and flow to prevent formation of air bubbles in plastisol).
7. Store plastisol in storage tank maintained under light vacuum.
8. Transfer aluminum foil rolls to stack station 1 area.
9. Transfer Craneglass 230 rolls to stack station 2 area.
10. Transfer solar cell prefabricated arrays to stack station 3 area.
11. Transfer vinyl spacer button strip rolls to stack station 3 area.
12. Transfer glass sheet pallets to stack station 4 area.
13. Load aluminum foil roll on unwind stand at stack station 1 after removing empty roll core from previous roll.
14. Load Craneglass 230 roll on unwind stand at stack station 2 after removing empty roll core from previous roll.
15. Load solar cell prefabricated arrays on unload stand alongside stack station 3.
16. Load vinyl spacer button strip rolls on each of six unwind stands alongside stack station 3 after removing empty roll cores from previous rolls.
17. Load pallet stack of glass sheet on unload stand at stack station 4 after removing empty pallet from previous stack.
18. Advance empty, clean, and open casting frame to stack station 1 and index.
19. At stack station 1, automatically cut a 26 in. x 50 in. sheet of aluminum foil, and automatically index and place it on the cored bottom plate of the casting frame.
20. Advance casting frame.
21. Index casting frame between stack station 1 and stack station 2, lower gasketed "picture frame" into position on top of aluminum foil sheet, 25 in. x 49 in. inside dimensions of picture frame.
22. Advance casting frame to stack station 2 and index.
23. At stack station 2, automatically cut a 24 in. x 48 in. sheet of Craneglass 230, and automatically index and place it in the casting frame on top of the aluminum foil, leaving 1/2-inch borders all around between edges of sheet and picture frame.
24. Advance casting frame to stack station 3 and index.

25. Alongside stack station 3, automatically pick up a prefabricated 24 in. x 48 in. solar cell array, index and place it on a horizontal table surface, automatically cut one 1 in. x 1 in. vinyl spacer button from each of six rolls, automatically place six spacer buttons on solar cell array, one in each corner and one at the center of each long edge, and automatically pick up and transfer the solar cell array, with spacer buttons attached, to stack station 3.
26. At stack station 3, automatically index the prefabricated solar cell array, with spacer buttons attached, and place it in the casting frame on top of the Craneglass 230 sheet.
27. Advance casting frame to stack station 4 and index.
28. At stack station 4, automatically take one 26 in. x 50 in. glass plate from the pallet stack, leaving the interleaving behind, and automatically index and place it in the casting frame on top of the vinyl spacer buttons.
29. Advance casting frame.
30. Index casting frame, lower the cored top plate of the casting frame, and clamp the frame.
31. Advance casting frame to moving conveyor.
32. On moving conveyor, tilt the casting frame $45^{\circ}$ from horizontal (inlet port low point, overflow port high point).
33. Pump plastisol from storage tank to filling system supply tank.
34. On moving conveyor, start to fill casting frame with plastisol slowly through inlet port with aid of vacuum on overflow port.
35. On moving conveyor, stop plastisol flow to casting frame when plastisol level reaches overflow port.
36. On moving conveyor, start steam flow to top and bottom plates of casting frame.
37. On moving conveyor, heat to $350^{\circ}F$ for 5 minutes to fuse plastisol.
38. On moving conveyor, shut off steam, start cooling water flow to top and bottom plates of casting frame.
39. On moving conveyor, cool for five minutes.
40. On moving conveyor, shut off cooling water flow.
41. On moving conveyor, open casting frame, remove module assembly, place module on conveyor to inspection area.
42. On moving conveyor, clean and inspect casting frame for next cycle, return frame to horizontal position.

43. Convey potted module assembly to inspection area.

44. Inspect and trim potted module assembly.

45. Transfer to packaging area.

46. Package potted module assembly

47. Transfer to storage area.

48. Store potted module assembly.

49. Transfer to shipping area for shipment.

Based on the fabrication steps described in the production flow chart, the total process may be calculated. The Summary (Page 3-39) gives the results of this costing exercise and includes such factors as direct and indirect labor, utilities, freight, insurance, maintenance, etc. The cost of the casting technique so described is found to be \$6.47 per module of 2 foot by 4 foot dimensions or equivalently, \$0.81 per square foot.

The reader is referred to Appendix IX for the details and calculations used in the preparation of this process cost estimate.

## SUMMARY

SOLAR CELL ENCAPSULATION PROCESS
LIQUID CASTING METHOD

COST ESTIMATE

Solar cell encapsulation/casting/plastisol pottant/2 ft x 4 ft panels
Superstrate construction

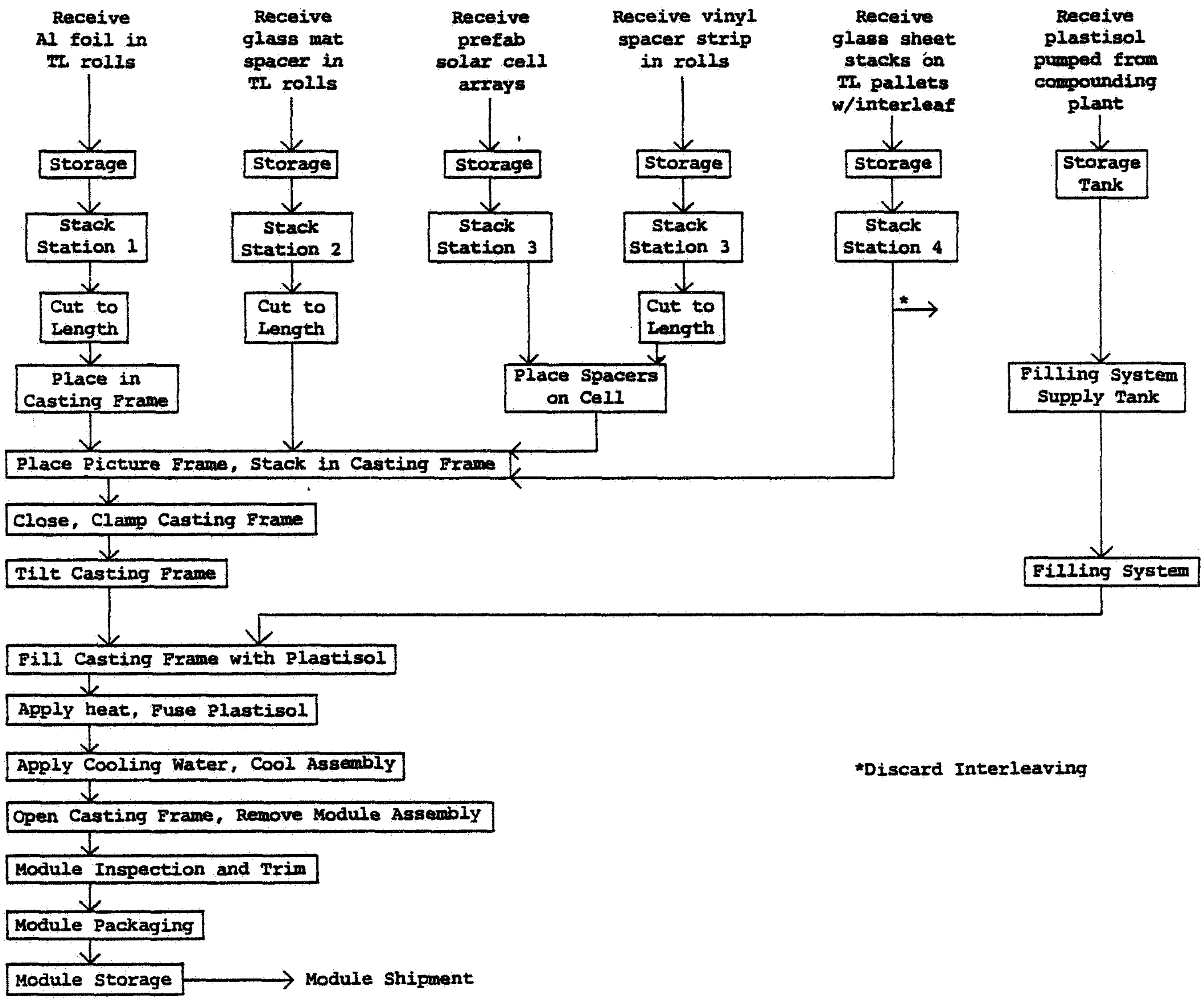
| | Annual $ | 6.25 million modules/yr<br>$ per module | 50 million sq. ft./yr<br>$ per sq. ft. | % |
|---|---|---|---|---|
| Operating Costs | | | | |
| Variable | | | | |
| Raw materials* | 24,466,100 | 3.9146 | 0.4893 | 66.98 |
| Direct labor | 2,693,300 | 0.4309 | 0.0539 | 7.37 |
| Fringes on direct labor, 30% | 808,000 | 0.1293 | 0.0162 | 2.21 |
| Utilities | 1,273,700 | 0.2038 | 0.0255 | 3.49 |
| Freight in and out | 982,600 | 0.1572 | 0.0197 | 2.69 |
| Packaging | 156,300 | 0.0250 | 0.0031 | 0.43 |
| Maintenance supplies, 1% of 16,765,500 | 167,700 | 0.0268 | 0.0034 | 0.46 |
| Maintenance labor, 1% of 16,765,500 | 167,700 | 0.0268 | 0.0034 | 0.46 |
| Other supplies, 2% of 24,466,100 | 489,300 | 0.0783 | 0.0098 | 1.34 |
| By products credits | --- | --- | --- | --- |
| | 31,204,700 | 4.9928 | 0.6241 | 85.43 |
| Fixed | | | | |
| Indirect labor, 0.6 x direct labor | 1,616,000 | 0.2586 | 0.0323 | 4.42 |
| Fringes on indirect labor, 30% | 484,800 | 0.0776 | 0.0097 | 1.33 |
| Depreciation | 2,384,600 | 0.3815 | 0.0477 | 6.53 |
| Insurance and taxes, 3% of 16,765,500 | 503,000 | 0.0805 | 0.0101 | 1.38 |
| Maintenance supplies, 1% of 16,765,500 | 167,700 | 0.0268 | 0.0034 | 0.46 |
| Maintenance labor, 1% of 16,765,500 | 167,700 | 0.0268 | 0.0034 | 0.46 |
| | 5,323,800 | 0.8518 | 0.1065 | 14.57 |
| Manufacturing Cost* | 36,528,500 | 5.8446 | 0.7306 | 100.00 |
| Working capital* 2,852,200 | | | | |
| ROI before tax at 20% of 16,765,500 + 2,852,200 | 3,923,500 | 0.6277 | 0.0784 | |
| Manufacturing Cost + ROI* | $\boxed{40,452,000*}$ | $\boxed{6.4723*}$ | $\boxed{0.8090*}$ | |

| Capital equipment and buildings | Life | Annual Depreciation |
|---|---|---|
| 1,008,000 | 2 yrs | $ 504,000 |
| 11,767,500 | 7 yrs | 1,681,100 |
| 3,990,000 | 20 yrs | 199,500 |
| 16,765,500 | | $2,384,600 |

*Excludes solar cell arrays

Cost based on:
Pottant: PVC Plastisol
Design: Superstrate
Size: 2 ft x 4 ft

PRODUCTION FLOW CHART
SOLAR CELL ENCAPSULATION PROCESS
LIQUID CASTING TECHNIQUE



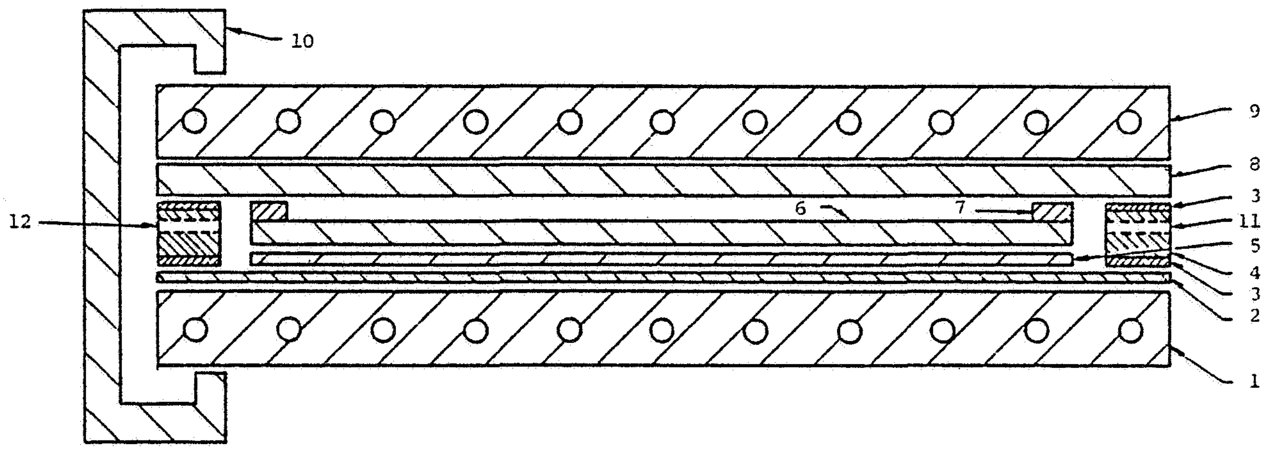



FIGURE 1

ENCAPSULATION FRAME
LIQUID CASTING TECHNIQUE

1. Bottom plate, cored for heating and cooling.
2. Aluminum foil.
3. Frame gasket
4. Frame
5. Glass mat spacer
6. Solar cell
7. Spacer buttons
8. Glass plate
9. Top plate, cored for heating and cooling
10. Clamp
11. Inlet port
12. Overflow port

APPENDIX

Appendix I

MANUFACTURING COST ESTIMATE
EVA SHEET, CLEAR

CALCULATIONS

OPERATING COSTS

1. Raw Materials

| Compound | Parts | Pounds | | $/Lb. | | Total RMC |
|---|---|---|---|---|---|---|
| Elvax 150 | 100 | 8,517,649 | @ | $0.5975 | = | 5,089,295 |
| Lupersol 101 | 1.5 | 127,765 | @ | 7.10 | = | 907,132 |
| Naugard P | 0.2 | 17,035 | @ | 0.68 | = | 11,584 |
| Cyasorb UV531 | 0.3 | 25,553 | @ | 5.10 | = | 130,320 |
| Tinuvin 770 | 0.1 | 8,518 | | 10.50 | = | 89,439 |
| | 102.1 | 8,696,520 | | | | $6,227,770/yr. |

$$250{,}000\ \frac{\text{ft.}^2}{\text{Day}} \times 0.020\ \text{in.} \times 0.966 \times 62.4\ \frac{\text{lb.}}{\text{ft.}^3} \times \frac{1\ \text{ft.}}{12\ \text{in.}} = 25{,}116\ \text{lbs./day net}$$

$$25{,}116\ \frac{\text{lbs.}}{\text{Day}} \times \frac{1\ \text{day}}{24\ \text{hr.}} \times \frac{1}{0.95\ \text{yield}} \times \frac{1}{0.85\ \text{eff.}} = 1{,}296\ \text{lbs./hr. line cap}$$

Use 4.5 inch extruder, line cap 1300 lbs./hr.
Line output 1300 lbs./hr. x 0.95 x 0.85 = 1050 lbs./hr net
1050 x 24 = 25,200 lbs./day net
25,200 x 340 = 8,568,000 lbs./yr. net

$$8{,}568{,}000\ \underline{\text{lbs.}} \times \frac{1\ \text{ft.}^3}{0.966 \times 62.4} \times \frac{1}{0.020\ \text{in.}} \times \frac{12\ \text{in.}}{\text{ft.}} = 85.284\ \text{million ft.}^2\text{/yr at 20 mils}$$

Material used, at 105% shrinkage 1.015 x 8,568,000 = 8,696,520 lbs./yr.

$$\frac{\$6{,}227{,}770}{\text{yr.}} \times \frac{1\ \text{yr.}}{85\text{-}284 \times 10^6\ \text{ft.}^2} = \$0.0730/\text{ft.}^2\ (20\ \text{mils})$$

2. Release Paper: 85.284 million ft.$^2$/yr. + 1.5% shrinkage

$$85.284 \times 10^6\ \frac{\text{ft.}^2}{\text{yr.}} \times 1.015 \times \frac{25\ \text{lbs.}}{3000\ \text{ft.}^2} \times \frac{\$0.55}{\text{lb.}} = \$396{,}748/\text{yr.}$$

Other supplies 0.02 x 6,227,770 = 124,555

521,303

Use $521,300/yr.

3. Utilities

Electricity: HP

| | |
|---|---|
| 40 | Blender |
| 300 | Extruder |
| 150 | Other HP |
| 490 x 0.746 = 366 KW | |
| 150 | KW Heaters |
| 516 | KW |

$$516 \text{ KW} \times \frac{340 \times 24 \text{ hrs.}}{\text{yr.}} \times \frac{\$0.04}{\text{Kwh}} = \$168,422/\text{yr.}$$

Assume other utilities at 20% of 168,422 = 33,684

202,106

Use $202,100

4. Freight

Freight in is prepaid on all materials except release paper.

$$\text{Release paper } \frac{85.284 \times 10^6 \times 1.015 \times 25}{3,000} = 721,361 \text{ lbs./yr.}$$

$$721,361 \frac{\text{lbs.}}{\text{yr.}} \times \frac{\$0.03}{\text{lb.}} = \$21,641/\text{yr.}$$

Freight out - wheeled racks with extruded sheet in rolls transferred to adjacent solar panel plant, no freight charge.

Total freight: use $21,600/yr.

5. Packaging

Extruded sheet in rolls transferred to adjacent solar panel plant on wheeled racks, no packaging charge.

6. EVA Storage Silo

Average EVA inventory 14 days at 25,200 lbs./day = 352,800 lbs.

$$352,800 \text{ lbs.} \times \frac{1 \text{ ft.}^3}{35 \text{ lbs.}} = 10,080 \text{ ft.}^3$$

Assume capacity 1.25 times average inventory, 1.25 x 10,080 = 12,600 ft.$^3$

1978 Butler 12'D. x 48'H. coated steel silo with accessories - $7,841, 5,000 ft.$^2$

Assume 3 x 5,000 = 15,000 ft.$^2$

3 x 7,841 x 1.10 inflation factor = 25,875

Use $25,900

7. Roll Shipping Racks

Max output 1,300 obs./hr.
Assume 3 in. ID core, 3-1/2" OD
Assume roll OD 24", length 60 in.
0.020 EVA + 0.002 in. release paper per turn = 0.022 in.

$$\frac{0.020}{0.022} \times \frac{1^{T}}{4} (24^2 - 3.52) \times 60 \text{ in.}^3 \times \frac{1 \text{ ft.}^3}{1728 \text{ in.}^3} \times 0.966 \times 62.4 \frac{\text{lb.}}{\text{ft.}^3}$$

842 lbs. EVA/roll

$$\frac{1300 \times 24}{842} = 37 \text{ rolls/day (max)}$$

Assume 50 roll shipping racks, wheeled, @ \$400 = \$20,000

8. Direct Labor, Annual

| Description | Number | Rate | Hours | Total |
|---|---|---|---|---|
| Extruder Operator | 1 | 5.50 | 340x24 | 44,880 |
| Helpers | 2 | 4.50 | 340x24 | 73,440 |
| Raw material & finished product handler | 1 | 4.50 | 340x24 | 36,720 |
| Shift supervisor/mechanic | 1 | 7.00 | 340x24 | 57,120 |
| Material blender/relief | 1 | 5.50 | 340x24 | 44,880 |
| | 6 | | | 257,040 |
| Average 5% shift differential | | | | 12,852 |
| | | | | 269,892 |

Average shift work week is $\frac{168}{4} = 42$ hours per week

Overtime premium $\frac{1}{2} \times \frac{2}{24} \times 269,892$ — 6,426

276,318

Use \$276,300

Total number 6 x 4 = 24

9. Working Capital

Raw material $\frac{14}{340}$ (6,227,800 + 521,300) = 277,904

+ Work in process $\frac{1}{340} \times 7,783,300$ = 22,892

+ Finished product $\frac{1}{340} \times 7,783,300$ = 22,892

+ Receivables $\frac{1}{12} \times \frac{7,783,300}{0.80}$ = 810,760

- Payables $\frac{1}{12} \times 7,783,300$ = -648,608

485,840

Use \$485,800

10. Buildings

Peroxide storage $\frac{127{,}765 \text{ lbs./yr.}}{340 \text{ days/yr.}} = 376$ lbs./day

$\frac{376}{200} =$ 2 drums per day

10 x 200 lb. drums = 2000 lbs. min. shipment

Assume shipment per 2 weeks - 14 x $\frac{376}{200}$ = 27 drums per shipment

Assume 40 x 200 lbs. drums per shipment, 40 ft. x 8 ft. = 320 ft.$^2$

Assume need 2 x 320 = 640 ft.$^2$

640 ft.$^2$ x \$30/ft.$^2$ = \$19,200

Main Building

Raw material storage 10 x 40 = 400 ft.$^2$ /TL

| | | |
|---|---|---|
| Assume 4TL - 4 x 400 | | =1600 ft.$^2$ |
| Plan equal space for aisles | | 1600 |
| | | 3200 |
| Processing - extrusion | 25x100 | 2500 |
| weighing, blending | 50x50 | 2500 |
| Shipping | 40x40 | 1600 |
| Officer | 20x100 | 2000 |
| Shop | 20x40 | 800 |
| Locker/lunchroom | 20x60 | 1200 |
| | | 13,800 |

13,800 x \$30/ft.$^2$ = \$414,000

414,000 + 19,200 = \$433,200

Use \$433,000

11. Capital Equipment Costs[a]

1. 54,000 Blender, 300 ft.$^2$
2. 3,500 Hopper
3. - Hopper
4. 116,000 4.5 inch extruder
5. 28,000 Sheet die
6. 199,000 Haul off, thickness control, paper pay-off

11. Capital Equipment Costs (Continued)

| | | |
|---|---|---|
| 7. | 42,800 | Winder |
| 8. | 15,000 | Edge trim and granulator |
| 9. | 10,000 | Car unloader |
| 10. | 25,900 | Storage silos |
| 11. | 10,000 | EVA transfer system |
| 12. | 15,000 | EVA weigh hopper |
| 13. | 2,000 | Hopper |
| 14. | 5,000 | Scale |
| - | 20,000 | Roll shipping racks, wheeled (50) |
| | 545,700 | |
| | 136,400 | Installation at 25% (incl. freight and sales tax) |
| | 682,100 | |
| | 68,200 | Engineering at 10% |
| | 750,300 | |
| | 112,600 | Auxiliary plant equipment, spares, 15% |
| | 862,900 | |
| 15,16. | 433,000 | Buildings |
| | 1,295,900 | Total |

(a) Numbers correspond to the items shown on the production flow chart.

Appendix II

MANUFACTURING COST ESTIMATES
EVA SHEET, PIGMENTED

CALCULATIONS

1. Raw Materials

| Compound | Parts | Pounds | | $/Lb. | | RMC |
|---|---|---|---|---|---|---|
| Elvax 150 | 100 | 7,978,459 | @ | 0.5975 | = | 4,767,129 |
| Lupersol 101 | 1.5 | 119,677 | @ | 7.10 | = | 849,707 |
| Kadox 15 ZnO | 5 | 398,923 | @ | 0.45 | = | 179,515 |
| Ferro AM105 | 0.5 | 39,892 | @ | 3.45 | = | 137,627 |
| RF-3 $TiO_2$ | 2.0 | 159,569 | @ | 0.545 | = | 86,965 |
| | 109.0 | 8,696,520 | | | | $6,020,943/yr. |

$$250{,}000\ \frac{\text{ft.}^2}{\text{day}} \times 0.020\ \text{in.} \times 0.981 \times 62.4\ \frac{\text{lb.}}{\text{ft.}^3} \times \frac{1\ \text{ft.}}{12\ \text{in.}} = 25{,}506\ \text{lbs./day net}$$

$$25{,}506\ \frac{\text{lbs.}}{\text{day}} \times \frac{1\ \text{day}}{24\ \text{hr.}} \times \frac{1}{0.95\ \text{yield}} \times \frac{1}{0.85\ \text{eff.}} = 1316\ \text{lbs./hr. line cap}$$

Use 4.5 inch extruder, line cap 1300 lbs./hr.

Line output 1300 lbs./hr. x 0.95 x 0.85 = 1050 lbs./hr net
1050 x 24 = 25,200 lbs./day net
25,200 x340 = 8,568,000 lbs./yr. net

$$8{,}568{,}000\ \frac{\text{lbs.}}{\text{yr.}} \times \frac{1\text{ft.}^3}{0.981 \times 62.4\ \text{lbs.}} \times \frac{1}{0.020\ \text{in.}} \times \frac{12\ \text{in.}}{\text{ft.}} = 83.980\ \text{million ft.}^2/\text{yr. at 20 mils}$$

Material used, at 1.5% shrinkage 1.015 x 8,568,000 = <u>8,696,520</u> lbs./yr.

$$\frac{\$6{,}020{,}943}{\text{yr.}} \times \frac{1\ \text{yr.}}{83.980 \times 10^6\ \text{ft.}^2} = \$0.0717/\text{ft.}^2\ (20\ \text{mils})$$

2. <u>Release paper:</u> 83.980 million $ft.^2$/yr. + 1.5% shrinkage

$$83.980 \times \frac{10^6\ \text{ft.}^2}{\text{yr.}} \times 1.015 \times \frac{25\ \text{lbs.}}{3000\ \text{ft}^2} \times \frac{\$0.55}{\text{lb.}} = \$390{,}682/\text{yr.}$$

Other supplies 0.02 x 6,020,943 = <u>120,419</u>
511,101
<u>Use $511,100/yr.</u>

3. Utilities

Electricity: HP

| | |
|---|---|
| 20 | Blender |
| 30 | Time screw extruder |
| 40 | Blender |
| 300 | Extruder |
| 200 | Other HP |
| 590 | x 0.746 = 440 KW |
| | 25 KW heaters |
| | 150 KW heaters |
| | 615 KW |

$$615 \text{ KW} \times \frac{340 \times 24 \text{ hrs.}}{\text{yr.}} \times \frac{\$0.04}{\text{Kwh}} = \$200{,}736/\text{yr.}$$

Assume other utilities at 20% of 200,736 = 40,147

$240,883/yr.

Use $240,900

4. Freight

Freight in is prepaid on all materials except release paper

$$\text{Release paper } \frac{83.980 \times 10^6 \times 1.015 \times 25}{3000} = 710{,}331 \text{ lbs./yr.}$$

$$710{,}331 \frac{\text{lbs.}}{\text{yr.}} \times \frac{\$0.03}{\text{lb.}} = \$21{,}310/\text{yr.}$$

Freight out - wheeled racks with extruded sheet in rolls transferred to adjacent solar panel plant, no freight charge.

Total freight: use $21,300/yr.

5. Packaging

Extruded sheet in rolls transferred to adjacent solar panel plant on wheeled racks, no packaging charge.

6. EVA Storage Silo

Average EVA inventory 14 days at 25,200 lbs./day = 352,800 lbs.

$$352{,}800 \text{ lbs.} \times \frac{1 \text{ ft.}^2}{35 \text{ lb.}} = 10{,}080 \text{ ft.}^3$$

Assume capacity 1.25 times average inventory

$1.25 \times 10{,}080 = 12{,}600 \text{ ft.}^3$

1978 Butler 12'D x 48'H coated steel silo with accessories - $7,841, 5,000 ft.$^3$

Assume $3 \times 5{,}000 = 15{,}000 \text{ ft.}^3$

3 x 7,841 x 1.10 inflation factor = 25,875

Use $25,900

7. Roll Shipping Racks

Max output 1300 lbs./hr.

Assume 3 in. ID core, 3-1/2" OD
Assume roll OD 24 in., length 60 in.
0.020 EVA + 0.002 in. release paper in turn = 0.022 in.

$$\frac{0.020}{0.022} \times \frac{\pi}{4} (24^2 - 3.5^2) \times 60 \text{ in.}^3 \times \frac{1 \text{ ft.}^3}{1728 \text{ in.}^3} \times 0.981 \times 62.4 \frac{\text{lb.}}{\text{ft.}^3} =$$

856 lbs. EVA/roll

$$\frac{1300 \times 24}{856} = 37 \text{ rolls/day (max)}$$

Assume 50 roll shipping racks, wheeled, @ \$400 = \$20,000

8. Direct Labor, Annual

| Description | Number | Rate | Hours | Total |
|---|---|---|---|---|
| Extruder operator | 2 | 5.50 | 340x24 | 89,760 |
| Helper | 2 | 4.50 | 340x24 | 73,440 |
| Raw material & finished product handler | 1 | 4.50 | 340x24 | 36,720 |
| Shift supervisor | 1 | 7.00 | 340x24 | 57,120 |
| Mechanic | 1 | 6.00 | 340x24 | 48,960 |
| Material blender/relief | 1 | 5.50 | 340x24 | 44,880 |
| | 8 | | | 350,880 |
| Average 5% shift differential | | | | 17,544 |
| | | | | 368,424 |

Average shift work week is $\frac{168}{4}$ = 42 hours per week

Overtime premium $\frac{1}{2} \times \frac{2}{42} \times 368{,}424$ — 8,772

377,196

Use \$377,200

Total number 8 x 4 = 32

9. Working Capital

| | | |
|---|---|---|
| Raw Material $\frac{14}{340}$ (6,020,900 - 511,100) | = | 268,965 |
| + Work in process $\frac{1}{340} \times 7{,}936{,}700$ | = | 23,343 |
| + Finished product $\frac{1}{340} \times 7{,}936{,}700$ | = | 23,343 |
| + Receivables $\frac{1}{12} \times \frac{7{,}936{,}700}{0.80}$ | = | 826,740 |
| - Payables $\frac{1}{12} \times 7{,}936{,}700$ | = | -661,392 |
| | | 480,999 |

Use \$ 481,000

10. Buildings

Peroxide storage $\frac{119,677 \text{ lbs./yr.}}{340 \text{ days/yr.}} = 352$ lbs./day

$\frac{352}{200} =$ 2 drums per day

10 x 200 lb. drums = 2000 lbs. min. shipment

Assume shipment per 2 weeks, 14 x $\frac{352}{200}$ = 25 drums per shipment

Assume 40 x 200 lbs. drums per shipment, 40 ft. x 8 ft. = 320 $ft.^2$

Assume used 2 x 320 = 640 $ft.^2$

640 $ft.^2$ x \$30/$ft.^2$ = \$19,200

Main Building

| | | |
|---|---|---|
| Raw material storage, 10 x 40 = 400 $ft.^2$/TL | | |
| Assume 8 TL | 8 x400 = | 3200 $ft.^2$ |
| Plus equal space for aisles | | 3200 |
| | | 6400 |
| Processing extrusion | 2 x 25 x 100 | 5000 |
| weighing, blending | 2 x 50 x 50 | 5000 |
| Shipping | 40 x 40 | 1600 |
| Offices | 20 x100 | 2000 |
| Shop | 20 x 40 | 800 |
| Locker/lunch room | 20 x 60 | 1200 |
| | | 22,000 |

22,000 x \$30/$ft.^2$ = \$660,000

660,000 + 19,200 = \$679,200

Use \$679,000

11. Capital Equipment Costs[a]

1. 33,000 Blender, 150 $ft.^2$
2. 2,000 Hopper
3. 3,000 Feeder
4. 207,000 Twin screw compounding extruder
5. 2,000 Strand die
6. 15,000 Pelletizer
7. 5,000 Transfer system
8. 54,000 Blender, 300 $ft.^3$
9. 3,000 Hopper

11. Capital Equipment Costs (Continued)

| | | |
|---|---|---|
| 10. | - | Hopper |
| 11. | 116,000 | 4.5 inch extruder |
| 12. | 28,000 | Sheet die |
| 13. | 119,000 | Haul off, thickness control, paper pay-off |
| 14. | 42,800 | Winder |
| 15. | 15,000 | Edge trim and granulator |
| 16. | 10,000 | Car unloader |
| 17. | 25,900 | Storage silos |
| 18. | 10,000 | EVA transfer system |
| 19. | 15,000 | EVA weight hopper |
| 20. | 2,000 | Hopper |
| 21. | 2,000 | Hopper |
| 22. | 1,000 | Hopper |
| 23. | 5,000 | Scale |
| 24. | 5,000 | Scale |
| | 20,000 | Roll shipping racks, wheeled (50) |
| | 820,700 | |
| | 205,200 | Installation at 25% (incl. freight and sales tax) |
| | 1,025,900 | |
| | 102,600 | Engineering at 10% |
| | 1,128,500 | |
| | 169,300 | Auxiliary plant equipment, spares, 15% |
| | 1,297,800 | |
| 25,26. | 679,000 | Buildings |
| | 1,976,800 | Total |

(a) Numbers correspond to items on production flow chart.

Appendix III

EPDM SHEET
MANUFACTURING COST ESTIMATES
CALCULATIONS - SPECIFIC GRAVITY

1. Production

| Compound | Parts/ Specific Gravity | | | |
|---|---|---|---|---|
| Nordel 1320 (EPDM) | 100/0.860 | = | 116.2791 | |
| Lupersol 231 | 1.0/0.907 | = | 1.1025 | |
| Cab-O-Sil MS-7 | 2.0/2.2 | = | 1.3636 | |
| Tinuvin 770 | 0.1/1 | = | 0.1000 | |
| Cyasorb UV-531 | 0.3/1 | = | 0.3000 | Specific Gravity |
| Goodrite 3114 | 0.2/1.03 | = | 0.1942 | Compound |
| | 104.6 | / | 119.3394 | = 0.8765 |

$$250{,}000\ \frac{\text{ft.}^2}{\text{day}} \times 0.020\ \text{in.} \times 0.8765 \times \frac{62.4\ \text{lb.}}{\text{ft.}^3} \times \frac{1\ \text{ft.}}{12\ \text{in.}} = 22{,}789\ \text{lb./day net}$$

$$22{,}789\ \frac{\text{lbs.}}{\text{day}} \times \frac{1\ \text{day}}{24\ \text{hr.}} \times \frac{1}{0.95\ \text{yield}} \times \frac{1}{0.85\ \text{eff.}} = 1176\ \text{lbs./hr. line cap.}$$

$$\text{3D Banbury cap. } \frac{140\ \text{lb.}}{6\ \text{min.}} \times \frac{60\ \text{min.}}{\text{hr.}} = 1400\ \text{lbs./hr.}$$

Line output 1400 x 0.95 x 0.85 = 1130 lbs./hr. net
1130 x 24 = 27,120 lbs./day net
2712 x340 = 9,220,800 lbs./yr. net

$$9{,}220{,}800\ \text{lbs.} \times \frac{1\ \text{ft.}^3}{0.8765 \times 62.4\ \text{lb.}} \times \frac{1}{0.020\ \text{in.}} \times \frac{12\ \text{in.}}{\text{ft.}} = 101.154\ \text{million ft.}^2/\text{yr. at 20 mils}$$

2. Raw Materials

Material used, at 1.5% shrinkage, 1.015 x 9,220,800 = 9,359,112 lbs./yr.

| Compounds | Parts | Pounds | | $/Lb. | | RMC |
|---|---|---|---|---|---|---|
| Nordel 1323 | 100 | 8,947,525 | x | 0.70 | = | 6,263,268 |
| Lupersol 231 | 1 | 89,475 | x | 3.70 | = | 331,058 |
| Cab-O-Sil MS-7 | 3 | 268,426 | x | 1.85 | = | 496,588 |
| Tinuvin 770 | 0.1 | 8,948 | x | 10.50 | = | 93,954 |
| Cyasorb OV5-1 | 0.3 | 26,843 | x | 5.10 | = | 136,899 |
| Goodrite 3114 | 0.2 | 17,895 | x | 3.19 | = | 57,085 |
| | 104.6 | 9,359,112 | | | | $7,378,852/yr. |

$$\$7{,}372{,}852\ \frac{}{\text{yr.}} \times \frac{1\ \text{yr.}}{101.154 \times 10^6\ \text{ft.}^2} = \$0.0729/\text{ft.}^2\ (20\ \text{mils})$$

3. Release Paper

Plus release paper, 101.154 million $ft.^2$/yr. + 1.5% shrinkage

$$101.154 \times \frac{10^6 \text{ ft.}^2}{\text{yr.}} \times 1.015 \times \frac{25 \text{ lbs.}}{3000 \text{ ft.}} \times \frac{\$0.55}{\text{lbs.}} = \$470{,}577/\text{yr}$$

Other supplies 0.02 x 7,378,852 = 147,577

$618,154/yr

4. Direct Labor, Annual

| Description | Number | Rate | Hours | Total |
|---|---|---|---|---|
| Guillotine operator | 1 | 4.50 | 340x24 | 36,720 |
| Banbury operator | 1 | 5.00 | 340x24 | 40,800 |
| Calender train operator | 1 | 5.50 | 340x24 | 44,880 |
| Calender train helpers | 2 | 4.50 | 340x24 | 73,440 |
| Raw material & finished product handler | 1 | 4.50 | 340x24 | 36,720 |
| Shift supervisor/mechanic | 1 | 7.00 | 340x24 | 57,120 |
| Relief | 1 | 5.00 | 340x24 | 40,800 |
| | 8 | | | 330,480 |
| Average 5% shift differential | | | | 16,524 |
| | | | | 347,004 |

Average shift work week is $\frac{168}{4}$ = 42 hours per week

Overtime premium $\frac{1}{2} \times \frac{2}{42} \times 347{,}004$ 8,262

355,266

Use $355,300

Total number 8 x 4 = 32

5. Capital Equipment Costs[(a)]

| | | |
|---|---|---|
| 1. | 250,000 | 3D Banbury mixer |
| 2. | 160,000 | 22 x 60 2 roll mill |
| 3. | 300,000 | 24 x68 2 roll calender |
| 4. | 70,000 | Calender train - take off, cool, wind |
| - | 70,000 | Conveyor |
| 5. | 9,000 | Guillotine cutter |
| 6. | 5,000 | Scale |
| - | 20,000 | Roll shipping racks, wheeled |
| | 884,000 | Plant equipment |
| | 265,200 | Installation at 30% (incl. freight and sales tax) |
| | 1,149,200 | |
| | 114,900 | Engineering at 10% |
| | 1,264,100 | |
| | 189,600 | Auxiliary plant equipment, spares 15% |
| | 1,453,700 | |
| 7&8 | 470,000 | Buildings |
| | 1,923,700 | Total |

(a) Numbers correspond to items on production flow chart.

Appendix IV

MANUFACTURING COST ESTIMATE
ALIPHATIC POLYURETHANE
SYRUP, CLEAR

CALCULATIONS

1. Raw Materials

| | | |
|---|---|---|
| Quinn | Q-621 | 525 |
| Quinn | Q-626 | 146.5 |
| | | 671.5 |

Sp gr $\frac{8.6 \text{ lbs}}{\text{gal}} \times \frac{7.48 \text{ gal}}{\text{ft}^3} = 64.3 \text{ lb/ft}^3$

$250{,}000 \frac{\text{ft}^2}{\text{day}} \times 0.020 \text{ in} \times \frac{64.3 \text{ lbs}}{\text{ft}^3} \times \frac{1 \text{ ft}}{12 \text{ in}} = 26{,}792 \text{ lbs/day}$

26,792 x 340 = 9,109,280 lbs/yr

At 1.5% shrinkage 1.015 x 9,109,280 = 9,245, 919 lbs/yr

| | | | |
|---|---|---|---|
| Quinn Q-621 | 525 | 7,228,753 x 1.65 = | 11,927,442 |
| Quinn mod Q-626 | 146.5 | 2,017,166 x 1.25 = | 2,521,458 |
| | 671.5 | 9,245,919 | $14,448,900/yr |

14,448,900/250,000 x 340 - $\$0.1700/\text{ft}^2$ (20 mils)
250,000 x 340 = 85.00 million $\text{ft}^2$/yr (20 mils)

Supplies 0.02 x 14,448,900 = 288,978
use $289,000/yr

2. Direct labor, annual

| Description | Number | Rate | Hours | Total |
|---|---|---|---|---|
| Operator/mechanic | 1 | 5.50 | 340 x 24 | 44,880 |
| Helper | 1 | 4.50 | 250 x 8 | 9,000 |
| | | | | 53,880 |
| 5% shift differential on 44,880 | | | | 2,244 |
| | | | | 56,124 |

Average shift work week is $\frac{168}{4}$ = 42 hours per week

| | |
|---|---|
| Overtime premium $\frac{1}{2} \times \frac{2}{42}$ (44,880 ÷ 2,244) | 1,122 |
| | 57,246 |
| Use | $58,300 |

Total number 4 x 1 + 1 = 5

3. Working Capital

| | | |
|---|---|---|
| Raw material $\frac{14}{340}$ (14,448,900 + 289,000) | = | 606,855 |
| + Work in process $\frac{1}{340}$ x 14,926,200 | = | 43,901 |
| + Finished product | = | -0- |
| + Receivables $\frac{1}{12}$ x $\frac{14,926,200}{0.80}$ | = | 1,554,813 |
| - Payables $\frac{1}{12}$ x 14,926,200 | = | -1,243,850 |
| | | 961,719 |
| | Use | $ 961,800 |

4. Capital equipment costs[(a)]

| | | |
|---|---|---|
| 1 | 5,000 | Unload pump |
| 2 | 5,000 | Unload pump |
| 3 | 20,000 | Storage tank |
| 4 | 7,200 | Storage tank |
| 5 | 5,000 | Charge pump |
| 6 | 5,000 | Charge pump |
| 7 | 2,700 | Heat exchanger |
| 8 | 1,600 | Heat exchanger |
| 9 | 8,200 | Heated deaeration reservoir |
| 10 | 4,000 | Heated deaeration reservoir |
| 11 | | ( Metering/recycle pump |
| 12 | 14,000 | ( Metering/recycle pump |
| 13 | | ( Mixer/dispenser |
| -- | 8,500 | Vacuum pump |
| | 86,200 | |
| | 34,500 | Installation at 40% (incl. freight and sales tax) |
| | 120,700 | |
| | 18,100 | Engineering at 15% |
| | 138,800 | |
| | 27,800 | Auxiliary plant equipment, spares, 20% |
| | 166,600 | |
| -- | 135,000 | Building |
| | 301,600 | Total |

(a) Numbers correspon d to items on production flow chart.

Appendix V

MANUFACTURING COST ESTIMATE
PVC PLASTISOL
SYRUP, CLEAR

CALCULATIONS

1. Production

| Compound | Parts | | Specific Gravity | | | |
|---|---|---|---|---|---|---|
| Goodyear Pliovic WO-1 PVC | 100 | / | 1.4 | = | 72.4286 | |
| R&H Paraplex G-30 | 67.5 | | 1.10 | = | 61.3636 | |
| R&H Paraplex G-62 | 7.5 | | 0.993 | = | 7.4475 | |
| R&H Monomer X-970 | 25.0 | | 1.011 | = | 24,7280 | Specific |
| M&T Thermolite 42 | 2.0 | | 1.14 | = | 1.7544 | Gravity |
| Ciba Geigy Tinuvin P | 1.011 | | 1 | = | 1.0110 | Compound |
| | 203.011/ | | | | 167.7331 = 1.211 sp gr | |

$$250{,}000\ \frac{ft^2}{day} \times 0.020\ in \times 1.210 \times 62.4\ \frac{lb}{ft^3} \times \frac{1\ ft}{12\ in} = 31{,}460\ lb/day$$

$$31{,}460\ \frac{lbs}{day} \times \frac{1\ gal}{1.210 \times 8.345\ lb} = 3{,}116\ gal/day$$

Use Day Nauta mixer MBX1410, 1054 gal/shift x 3 shifts/day - 3,162 gal/day

$$3{,}162\ \frac{gal}{day} \times 1.210 \times 8.345\ \frac{lbs}{gal} \times 340\ \frac{days}{yr} = 11{,}018{,}400\ lbs/yr$$

2. Raw Materials

| Compound | Parts | Pounds | | $/lb | | RMC |
|---|---|---|---|---|---|---|
| Goodyear Pliovic WO-1 | 100 | 5,427,489 | x | 0.48 | = | 2,605,195 |
| R&H Paraplex G-30 | 67.5 | 3,663,555 | x | 0.75 | = | 2,747,666 |
| R&H Paraplex G-62 | 7.5 | 407,062 | x | 0.61 | = | 248,308 |
| R&H Monomer X-970 | 25.0 | 1,356,872 | x | 1.33 | = | 1,804,640 |
| M&T Thermolite 42 | 2.0 | 108,550 | x | 4.16 | = | 451,568 |
| Ciba Geigy Tinuvin P | 1.011 | 54,872 | x | 7.35 | = | 403,309 |
| | 203.011 | 11,018,400 | | | | $8,260,686/yr |

$8,260,686/11,018,400 = $0.7497/lb

$$10{,}855{,}567\ \frac{lbs}{yr} \times \frac{1\ ft^3}{1.210 \times 62.4\ lb} \times \frac{12\ in}{1\ ft} \times \frac{1}{0.020\ in} = 86.265\ \text{million}\ ft^2/yr$$
(20 mils)

$8{,}260{,}686/86.265 \times 10^6 = \$0.0958/ft^2$ (20 mils)

Supplies 0.02 x 8,260,686 = 165,214
Use $165,200/yr

3. Direct labor, annual

| Description | Number | Rate | Hours | Total |
|---|---|---|---|---|
| Operator | 1 | 5.50 | 340x24 | 44,880 |
| Helper | 1 | 4.50 | 340x24 | 36,720 |
| Material handler | 1 | 4.50 | 250x 8 | 9,000 |
| | | | | 90,600 |
| 5% shift differential on (44,880 ÷ 36,720) | | | | 4,080 |
| Average shift work week is $\frac{168}{4}$ = 42 hours per week | | | | |
| Overtime premium $\frac{1}{2}$ x $\frac{2}{42}$ (44,880 ÷ 36,720 ÷ 4,080) | | | | 2,040 |
| | | | | 96,720 |
| | | | Use | $96,700 |

Total number 4x2+1=9

4. Working capital

| | | |
|---|---|---|
| Raw material $\frac{14}{340}$ (8,260,700 + 165,200) | = | 346,949 |
| + Work in process $\frac{1}{340}$ x 8,781,900 | = | 25,829 |
| + Financial product $\frac{1}{340}$ x 8,781,900 | = | 25,829 |
| + Receivables $\frac{1}{12}$ x $\frac{8,781,900}{0.80}$ | = | 914,781 |
| - Payables $\frac{1}{12}$ x 8,781,900 | = | - 731,825 |
| | | 581,563 |
| | Use | $581,600 |

5. Capital equipment costs[a]

| | | |
|---|---|---|
| 1 | 5,000 | Unload pump |
| 2 | 5,000 | Unload pump |
| 3 | 5,000 | Unload pump |
| 4 | 9,800 | Storage tank |
| 5 | 4,200 | Storage tank |
| 6 | 5,700 | Storage tank |
| 7 | 5,000 | Charge pump |
| 8 | 5,000 | Charge pump |
| 9 | 5,000 | Charge pump |
| 10 | 5,000 | Meter |
| 11 | 5,000 | Meter |
| 12 | 5,000 | Meter |
| 13 | 5,000 | Scale |
| 14 | 15,000 | Bag dumper |
| 15 | 73,500 | Mixer/Deaerator |
| 16 | 5,000 | Transfer pump |
| 17 | 4,200 | Plasticol storage |
| 18 | 5,000 | Transfer pump |
| | 172,400 | |
| | 69,000 | Installation at 40% (incl. freight and sales tax) |
| | 241,400 | |
| | 36,200 | Engineering at 15% |
| | 277,600 | |
| | 55,500 | Auxiliary plant equipment, spares, 20% |
| | 333,100 | |
| 19 | 369,000 | Building |
| | 702,100 | Total |

(a) Numbers correspond to items on production flow chart.

Appendix VI

MANUFACTURING COST ESTIMATE
BUTYL ACRYLATE
SYRUP CLEAR

CALCULATIONS

1. Raw Materials

200,000 $ft^2$/day, 20 mils plastic pottant thickness

$$200{,}000 \frac{ft^2}{day} \times 340 \frac{days}{yr} \times 0.020 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{1.08 \times 62.4 \text{ lb}}{ft^3} = 7{,}637{,}760 \text{ lbs/yr}$$

Monomer requirements, at 1% loss in syrup preparation:

7,637,760 x 1.01 = 7,714,138 lbs/yr

| | | |
|---|---|---|
| 7,714,138 lbs/yr x $0.43/lb = | | $3,317,079/yr |
| Additives and inhibitor, 10% | | 331,708 |
| Raw materials | | 3,648,787/yr |
| | Use | $3,648,800/yr |

$$7{,}714{,}138 \frac{\text{lbs mon.}}{yr} \times \frac{1 \text{ yr}}{340 \times 24 \text{ hrs}} = 945.36 \text{ lbs/hr}$$

2. Production Rate

For 12 hrs residence time at liquid sp gr 0.894:

$$945.36 \frac{lbs}{hr} \times 12 \text{ hr} \times \frac{1 \text{ gal}}{0.894 \times 8.345 \text{ lb}} = 1520.6 \text{ gal}$$

At 20% head space and 33% conversion from sp gr 0.894 to 1.08:

$$\frac{1520.6}{0.80} = 1900.7 \text{ gal}$$

$$1900.7 \times \frac{0.894}{0.894+0.33\ (1.08-0.894)} = 1778.6 \text{ gal}$$

$$945.36 \frac{lbs}{hr} \times \frac{24 \text{ hr}}{day} \times \frac{1 \text{ gal}}{0.894 \times 8.345 \text{ lb}} = 3041.2 \text{ gal/day monomer}$$

$$945.36 \frac{lbs}{hr} \times \frac{1 \text{ gal}}{0.894 \times 8.345 \text{ lb}} = 126.72 \text{ gal/hr monomer}$$

126.72/60 = 2.112 gal/min, monomer

3. Utilities

Electricity

| | | |
|---|---|---|
| Pumps, assume 5 @ 5 HP | = | 25 HP |
| Agitators, assume 25 HP + 5 HP | = | 30 |
| | | 55 |
| Other, assume | | 45 |
| | | 100 HP |

$$100 \text{ HP} \times 0.746 \frac{\text{KW}}{\text{HP}} \times 24 \times 340 \frac{\text{hrs}}{\text{yr}} \times \frac{\$0.04}{\text{KWH}} = \$24{,}349/\text{yr}$$

Cooling water

Heat exchanger (excl. losses)

$$945.36 \frac{\text{lbs}}{\text{hr}} \times \frac{0.46 \text{ BTU}}{\text{lb deg F}} \times (80-30)^{\circ}\text{C} \times \frac{1.8^{\circ}\text{F}}{^{\circ}\text{C}} = 39{,}138 \text{ BTU/hr}$$

$$39{,}138 \frac{\text{BTU}}{\text{hr}} \times \frac{1 \text{ lb deg F}}{1 \text{ BTU}} \times \frac{1}{18^{\circ}\text{F}} = 2{,}174.3 \text{ lb cooling water/hr}$$

Reactor (excl. losses)

$$945.36 \frac{\text{lbs}}{\text{hr}} \times (80-20)^{\circ}\text{C} \times \frac{1.8^{\circ}\text{F}}{^{\circ}\text{C}} \times \frac{0.46 \text{ BTU}}{\text{lb deg F}} = 46{,}965 \text{ BTU/hr for heat up}$$

$$945.36 \frac{\text{lbs mon}}{\text{hr}} \times 0.33 \text{ polym} \times \frac{1 \text{ mole}}{128 \text{ gms}} \times \frac{18.5 \text{ kcal}}{\text{mole}} \times \frac{453.6 \text{ gms}}{\text{lb}} \times \frac{3.9683 \text{ BTU}}{\text{kcal}} =$$

81,162 BTU/hr heat released

81,161 - 46,965 = 34,197 BTU/hr to be removed

$$34{,}197 \frac{\text{BTU}}{\text{hr}} \times \frac{1 \text{ lb deg F}}{1 \text{ BTU}} \times \frac{1}{18^{\circ}\text{F}} = 1899.8 \text{ lb cooling water/hr}$$

$$(2{,}174.3 \times 1899.8) \frac{\text{lb}}{\text{hr}} \times \frac{1 \text{ gal}}{8.345 \text{ lb}} \times 24 \times 340 \frac{\text{hr}}{\text{yr}} = 3{,}983{,}781 \text{ gal water/yr}$$

$$3{,}983{,}781 \frac{\text{gal}}{\text{yr}} \times \frac{1 \text{ ft}^3}{7.481 \text{ gal}} \times \frac{\$0.25}{100 \text{ ft}^3} = \$1{,}331/\text{yr}$$

| | | |
|---|---|---|
| 24,349 + 1,331 | = | $25,680/yr |
| Other util at 30% of 25,680 | = | 7,704 |
| | | $33,384 |

Use $33,400/yr

4. Freight

Freight in on u-butyl acrylate monomer is prepaid; assume freight in on all other raw materials and supplies is either prepaid or negligible.

Freight out - assume casting syrup is pumped to adjacent solar panel plant, no freight charge.

5. Packaging

Assume casting syrup is pumped to adjacent solar panel plant, no packaging charge.

6. Direct labor, annual

| Description | Number | Rate | Hours | Total |
|---|---|---|---|---|
| Operator/mechanic | 1 | 5.50 | 340x24 | 44,880 |
| Helper | 2 | 4.50 | 340x24 | 73,440 |
| | 3 | | | 118,320 |
| Av. 5% shift differential on 118,320 | | | | 5,916 |
| | | | | 124,236 |
| Average shift work week is $\frac{168}{4}$ = 42 hours per week | | | | |
| Overtime premium $\frac{1}{2} \times \frac{2}{42} \times 124,236$ | | | | 2,958 |
| | | | | 127,194 |
| | | | | Use $127,200 |

Total number 4x3=12

7. Working capital

| | | |
|---|---|---|
| Raw material $\frac{14}{340}$ (3,648,800 + 73,000) | = | 153,251 |
| + Work in process $\frac{1}{340} \times 4,111,600$ | = | 12,093 |
| + Finished product $\frac{1}{340} \times 4,111,600$ | = | 12,093 |
| + Receivables $\frac{1}{12} \times \frac{4,111,600}{8}$ | = | 428,292 |
| - Payables $\frac{1}{12} \times 4,111,600$ | = | - 342,633 |
| | | 263,096 |
| | Use | $ 263,100 |

8. Capital equipment costs[(a)]

| | | |
|---|---|---|
| 1. | Transfer pump | 5,000 |
| 2. | Monomer storage tank | 20,000 |
| 3. | Weigh scale | 5,000 |
| 4. | Batch mixing tank | 5,000 |
| 5. | Transfer pump | 5,000 |
| 6. | Feed tank | 2,000 |
| 7. | Metering pump | 5,000 |
| 8. | Metering pump | 5,000 |
| 9. | Stirred polymerization kettle | 37,000 |
| 10. | Heat exchanger | 3,000 |
| 11. | Inhibitor feed tank | 1,000 |
| 12. | Metering pump | 5,000 |
| 13. | In line mixer | 10,000 |
| 14. | Syrup storage tank | 3,000 |
| | | 111,000 |
| | Auxiliary plant equipment, instruments, spares, 30% | 33,300 |
| | | 144,300 |
| | Installation at 40% (incl. freight and sales tax | 57,700 |
| | | 202,000 |
| | Engineering, 15% | 30,300 |
| | | 232,300 |
| 15. | Initiator storage building, 300 ft$^2$ @ \$30 ) | 159,000 |
| 16. | Process and storage building, 5000 ft$^2$ @ \$30) | |
| | | 391,300 |
| | Use | \$392,000 |

Appendix VII

MANUFACTURING COST CALCULATIONS
BUTYL ACRYLATE
SHEET, CLEAR
CALCULATIONS

1. Raw Materials

200,000 $ft^2$/day, 20 mils plastic sheet thickness

$$200{,}000\ \frac{ft^2}{day} \times 340\ \frac{days}{yr} \times 0.020\ in \times \frac{1\ ft}{12\ in} \times \frac{1.08x62.4\ lb}{ft^3} = 7{,}637{,}760\ lbs/yr$$

At 2% monomer losses in going from monomer to sheet, monomer requirements are 7,637,760 x 1.02 = 7,790,515 lbs/yr

| | | |
|---|---|---|
| 7,790,515 lbs/yr x $0.43/lb | = | $3,349,922/yr |
| Additives, 10% | | 334,992 |
| Raw materials | | $3,684,914/yr |
| | | Use $3,684,900/yr |

2. Release paper

$$200{,}000\ \frac{ft^2}{day} \times \frac{340\ days}{yr} \times 1.02 \times \frac{25\ lbs}{3000\ ft^2} \times \frac{\$0.55}{lb} = \$317{,}900/yr$$

| | | |
|---|---|---|
| Other supplies 0.02 x 3,684,900 d | = | 73,698 |
| | | 391,598 |
| | | Use $391,600/yr |

3. Production Rate

$$7{,}790{,}515\ \frac{lbs\ mon}{yr} \times \frac{1\ yr}{340x24\ hrs} = 954.72\ lbs/hr\ monomer$$

$$954.72\ \frac{lbs}{hr} \times \frac{1\ gal}{0.894 \times 8.345\ lb} = 127.97\ gal/hr\ monomer$$

127.97 x 24 = 3071.3 gal/day monomer

127.97/60 = 2.133 gal/min monomer

4. Utilities

Electricity

| | | |
|---|---|---|
| 6 transfer or metering pumps @ 5HP | = | 30HP |
| 2 melt pumps @ 15HP | = | 30 |
| 2 stirrer motors, 25 + 15 | = | 40 |
| 1 extruder drive and heaters | = | 20 |
| | | 130 |
| Other | = | 70 |
| | | 200HP |

$$200HP \times \frac{0.746\ KW}{HP} \times 24x340\ \frac{hrs}{yr} \times \frac{\$0.04}{KWH} = \$48{,}699/yr$$

Gas (for Therminol heater)

$$955\ \frac{\text{lbs}}{\text{hr}} \times 50^\circ\text{C} \times \frac{1.8^\circ\text{F}}{^\circ\text{C}} \times \frac{0.5\ \text{BTU}}{\text{lb deg F}} = 43{,}000\ \text{BTU/hr}$$

$$43{,}000 \times 340 \times 24 = 350.88 \times 10^6\ \text{BTU/yr}$$

$$350.88 \times 10^6\ \frac{\text{BTU}}{\text{yr}} \times \frac{1\ \text{ft}^3\ \text{nat gas}}{1000\ \text{BTU}} \times \frac{\$3.00}{1000\ \text{ft}^3} = \$1053/\text{yr}$$

Cooling water

Stirred polymerization reactor

Heat absorbed

$$954.72\ \frac{\text{lbs}}{\text{hr}} \times 0.33\ \text{polym} \times \frac{1\ \text{mole}}{128\ \text{gms}} \times \frac{18.5\ \text{K cal}}{\text{mole}} \times \frac{453.6\ \text{gm}}{\text{lb}} \times \frac{3.9683\ \text{BTU}}{\text{K cal}} =$$

$$81{,}965\ \text{BTU/hr}$$

Heat to be removed: $81{,}965 - 47{,}430 = 34{,}535$ BTU/hr

Second polymerization reactor

Heat absorbed

$$954.72\ \frac{\text{lbs}}{\text{hr}} \times (150\text{-}80)\ ^\circ\text{C} \times \frac{1.8^\circ\text{F}}{^\circ\text{C}} \times \frac{0.46\ \text{BTU}}{\text{lb}\ ^\circ\text{F}} = 55{,}336\ \text{BTU/hr}$$

Heat released

$$954.72\ \frac{\text{lbs}}{\text{hr}} \times (0.88\text{-}0.33)\ \text{polym} \times \frac{18.5 \times 453.6 \times 3.9683}{128}\ \frac{\text{BTU}}{\text{lb}} =$$

$$136{,}609\ \text{BTU/hr}$$

Heat to be removed: $136{,}609 - 55{,}336 = 81{,}273$ BTU/hr

Sheet cooling

$$954.72\ \frac{\text{lbs}}{\text{hr}} \times (200\text{-}20)^\circ\text{C} \times \frac{1.8^\circ\text{F}}{^\circ\text{C}} \times \frac{0.46\ \text{BTU}}{\text{lb deg F}} = 142{,}292\ \text{BTU/hr}$$

Vapor condenser

$$57.3\ \frac{\text{lbs}}{\text{hr}} \times (200\text{-}50)^\circ\text{C} \times \frac{1.8^\circ\text{F}}{^\circ\text{C}} \times \frac{0.46\ \text{BTU}}{\text{lb deg F}} = 7{,}117\ \text{BTU/hr}$$

$$57.3\ \frac{\text{lbs}}{\text{hr}} \times \frac{46\ \text{cal}}{\text{gm}} \times \frac{453.6\ \text{gm}}{\text{lb}} \times \frac{1\ \text{BTU}}{252\ \text{cal}} = 4{,}744\ \text{BTU/hr}$$

$$34{,}535 + 81{,}273 + 142{,}292 + 7{,}117 + 4{,}744 = 269{,}961\ \text{BTU/hr}$$

$$269{,}961\ \frac{\text{BTU}}{\text{hr}} \times \frac{1\ \text{lb deg F}}{\text{BTU}} \times \frac{1}{18^\circ\text{F}} \times \frac{1\ \text{gal}}{8.345\ \text{lb}} \times \frac{340\text{x}24\ \text{hr}}{\text{yr}} = 14{,}665{,}347\ \text{gal/yr}$$

Steam jet

$$\frac{20 \text{ gpm}}{660 \text{ lbs vapor}} \times 60 \text{ lbs vap} = 1.82 \text{ gpm water}$$

$$1.82 \text{ gpm} \times 60 \times 24 \times 340 \frac{\text{min}}{\text{yr}} = 891{,}072 \text{ gal/yr}$$

$$14{,}665{,}347 + 891{,}072 = 15{,}556{,}419 \text{ gal/yr}$$

$$15{,}556{,}419 \frac{\text{gal}}{\text{yr}} \times \frac{1 \text{ ft}^3}{7.481 \text{ gal}} \times \frac{\$0.25}{100 \text{ ft}^3} = \$5{,}199/\text{yr}$$

$$\text{Steam } \frac{330 \text{ lbs/hr}}{660 \text{ lbs/hr vap}} \times \frac{60 \text{ lbs vap}}{\text{hr}} = 30 \text{ lbs steam/hr}$$

$$\frac{30 \text{ lbs}}{\text{hr}} \times \frac{340\text{x}24 \text{ hr}}{\text{yr}} \times \frac{\$5.00}{1000 \text{ lb}} = \$1224/\text{yr}$$

| | | |
|---|---|---|
| 48,699 + 1,053 + 5,199 + 1,224 | = | $56,175/yr |
| Other utilities at 30% of 56,175 | = | 16,853 |
| | | 73,028 |
| | | Use $73,000/yr |

5. Freight in on n-butyl acrylate monomer is prepaid; assume freight in on all other raw materials and supplies except release paper is either prepaid or negligible.

Release paper

$$\frac{100{,}000 \times 340 \times 1.02 \times 25}{3{,}000} = 578{,}000 \text{ lbs/yr}$$

$$578{,}000 \frac{\text{lbs}}{\text{yr}} \times \frac{\$0.03}{\text{lb}} = \$77{,}340/\text{yr}$$

Freight out - wheeled racks with extruded sheet in rolls transferred to adjacent solar panel plant, no freight charge.

Total freight: Use $17,400/yr

6. Packaging

Extruded sheet in rolls transferred to adjacent solar panel plant on wheeled racks, no packaging charge.

7. Direct labor, annual

| Description | Number | Rate | Hours | Total |
|---|---|---|---|---|
| Shift supervisor/mechanic | 1 | 7.00 | 340x24 | 57,120 |
| Operator, polymerization | 1 | 5.50 | 340x24 | 44,880 |
| Helper, polymerization | 2 | 4.50 | 340x24 | 73,440 |
| Operator, sheet line | 1 | 5.50 | 340x24 | 44,880 |
| Helper, sheet line | 1 | 4.50 | 340x24 | 36,720 |
| Material handler/relief | 1 | 4.50 | 340x24 | 36,720 |
| | 7 | | | 293,760 |
| Average 5% shift differential | | | | 14,688 |
| | | | | 308,448 |

Average shift work week is $\frac{168}{4} = 42$ hours per week

Overtime premium $\frac{1}{2} \times \frac{2}{42} \times 308{,}448$ — 7,344

315,792

Use $315,800

Total number 7 x 4 = 28

8. Working capital

| | | |
|---|---|---|
| Raw material $\frac{14}{340}$ (3,684,900 + 391,600) | = | 167,856 |
| + Work in process $\frac{1}{340} \times 5{,}161{,}400$ | = | 15,181 |
| + Finished product $\frac{1}{340} \times 5{,}161{,}400$ | = | 15,181 |
| + Receivables $\frac{1}{12} \times \frac{5{,}161{,}400}{0.8}$ | = | 537,646 |
| - Payables $\frac{1}{12} \times 5{,}161{,}400$ | = | - 430,117 |
| | | 305,747 |
| | | Use $305,800 |

9. Capital equipment costs[a]

| | | |
|---|---|---|
| 1. | Transfer pump | 5,000 |
| 2. | Monomer storage tank | 20,000 |
| 3. | Weigh scale | 5,000 |
| 4. | Batch mixing tank | 5,000 |
| 5. | Transfer pump | 5,000 |
| 6. | Feed tank | 2,000 |
| 7. | Metering pump | 5,000 |
| 8. | Metering pump | 5,000 |
| 9. | Stirred polymerization kettle | 37,000 |
| 10. | Transfer pump | 5,000 |
| 11. | Second polymerization reactor | 48,000 |
| 12. | Melt pump | 44,000 |
| 13. | Melt preheater | 4,000 |
| 14. | Tower devolatilizer | 19,000 |
| 15. | Melt pump | 44,000 |
| 16. | Sheet die | 28,000 |
| 17. | Haul off, thickness control, paper pay-off | 199,000 |
| 18. | Winder | 43,000 |
| 19. | Trim recycle extruder, 2.5 in, w/screen changer | 35,000 |
| 20. | Oligomers condenser | 4,000 |
| 21. | Monomer condenser | 4,000 |
| 22. | Transfer pump | 5,000 |
| - | Vacuum jet | 2,000 |
| - | Roll shipping racks, wheeled (40) | 16,000 |
| - | Therminol system | 5,000 |
| | | 594,000 |
| | Auxiliary plant equipment instruments, spares, 30% | 178,000 |
| | | 772,000 |
| | Installation at 40% (incl freight and sales tax) | 309,000 |
| | | 1,081,000 |
| | Engineering, 15% | 162,000 |
| | | 1,243,000 |
| 23. | Initiator storage building, 300 $ft^2$ @ $30) | |
| 24. | Process and storage building, 12,000 $ft^2$ ) @ $30 ) | 369,000 |
| | Total | $1,612,000 |

(a) Numbers correspond to items on production flow chart.

Appendix VIII

MANUFACTURING COST ESTIMATE
SOLAR CELL ENCAPSULATION PROCESS
SHEET LAMINATION TECHNIQUE

CALCULATIONS

1. Raw Materials

Desired output $\frac{200,000 \text{ ft}^2}{\text{day}} \times \frac{1 \text{ panel}}{2 \times 4 \text{ ft}^2} \times )5 \times 52{=}10) \frac{\text{days}}{\text{yr}} = 6,250,000$ panels/yr

Assume 1% shrinkage and 5% rejects

Prefabricated solar cell arrays:

$$6,250,000 \frac{\text{panels}}{\text{yr}} \times \frac{24\text{x}48 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 53.157895 \text{ million ft}^2/\text{yr}$$

Hardboard panels:

$$6,250,000 \frac{\text{panels}}{\text{yr}} \times \frac{24\text{x}48 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 53.157895 \text{ million ft}^2/\text{yr}$$

Glass mat spacer:

$$6,250,000 \frac{\text{panels}}{\text{yr}} \times \frac{2 \text{ mats}}{\text{panel}} \times \frac{24\text{x}48 \text{ in}^2}{\text{mat}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 106.31579 \text{ million ft}^2/\text{y}$$

Korad film:

$$6,250,000 \frac{\text{panels}}{\text{yr}} \times \frac{26 \times 50 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 59.987208 \text{ million ft}^2/\text{yr}$$

Clear EVA sheet:

$$6,250,000 \frac{\text{panels}}{\text{yr}} \times \frac{26\text{x}50 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 59.987208 \text{ million ft}^2/\text{yr}$$

White EVA sheet:

$$6,250,000 \frac{\text{panels}}{\text{yr}} \times \frac{2 \text{ sheets}}{\text{panel}} \times \frac{26\text{x}50 \text{ in}^2}{\text{sheet}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} =$$

$$119.97442 \text{ million ft}^2/\text{yr}$$

Raw Material Costs follow:

Hardboard: $53.157895 \times 10^6 \frac{ft^2}{yr} \times \frac{\$0.10}{ft^2}$ = 5,315,790

Glass mat spacer: $106.31579 \times 10^6 \frac{ft^2}{yr} \times \frac{6.1\ lb}{17x22x550\ in^2} \times$

$\frac{144\ in^2}{ft^2} \times \frac{\$1.68}{lb}$ = 838,992

Korad film: $59.987208 \times 10^6 \frac{ft^2}{yr} \times \frac{\$0.05}{ft^2}$ = 2,999,360

Clear EVA: $59.987208 \times 10^6 \frac{ft^2}{yr} \times \frac{\$0.0954}{ft^2 \times 20\ mils} \times 18\ mils$ = 5,150,502

White EVA: $119.97442 \times 10^6 \frac{ft^2}{yr} \times \frac{\$0.1004}{ft^2 \times 20\ mils} \times 12\ mils$ = 7,227,259

21,531,903

Use $21,531,900/yr*

*Excludes solar cell arrays

2. Utilities

Assume each molding frame contains $30 \times 54 \times \frac{1}{2} \times 2 = 1620\ in^3$ steel

Theoretical BTU to heat up, each cycle:

$$1620\ in^3 \times \frac{0.284\ lb}{in^3} \times \frac{0.107\ BTU}{lb\ deg\ F} \times (140-50)^{\circ}C \times \frac{1.8^{\circ}F}{^{\circ}C} = 7975\ BTU/cycle$$

Cost of theoretical steam for heat up, at $4/1000 lb steam

$$7975 \frac{BTU}{cycle} \times \frac{\$4}{1000\ lb} \times \frac{1\ lb}{1000\ BTU} = \$0.0319/cycle$$

Assume cost to hold at temp equal to theoretical heat up = $0.0319

Assume heating efficiency is 50% 2 (0.0319+0.0319) = $0.1276

Assume equal cost for other utilities 0.1276+0.1276 = $0.2552/cycle

$$\frac{\$0.2552}{cycle} \times \frac{200{,}000}{8} \frac{panels}{day} \times \frac{250\ days}{yr} \times \frac{1\ cycle}{0.95\ panel} = \$1{,}679{,}000/yr$$

3. Freight

Assume no freignt in on EVA sheet or solar cell arrays.

Assume other raw materials received by truck, truckload is lesser of 40,000 lbs or 8.40x10 = 3200 cu ft, freight cost is $500 per TL.

Hardboard:

$$53.157895 \times 10^6 \frac{ft^2}{yr} \times \frac{0.120}{12} ft \times \frac{50 \ lb}{ft^3} \times \frac{\$500}{400{,}000 \ lbs} = \$332{,}237/yr$$

Korad:

$$59.987208 \times 10^6 \frac{ft^2}{yr} \times \frac{0.003}{12} ft \times \frac{1.2 \times 62.4 \ lb}{ft^3} \times \frac{\$500}{40{,}000 \ lbs} = 24.037$$

Glass mat spacer:

$$106.31579 \times 10^6 \frac{ft^2}{yr} \times \frac{0.005}{12} ft \times \frac{\$500}{0.75 \times 3200 \ ft^3} = \underline{9{,}229}$$

$$355{,}503$$

Assume other freight in is negligible.
Assume freight out is paid by customer.

Use $355,500/yr

4. Packaging

Assume corrugated board packaging, pallet, and overwrap costs are $2.00 per 100 modules

$$25{,}000 \frac{modules}{day} \times \frac{250 \ days}{yr} \times \frac{\$2.00}{100 \ modules} = \underline{\$125{,}000/yr}$$

5. Production

MOLD CYCLES

| Step | Operation | Time, Min - Sec |
|---|---|---|
| 1 | Stack station 1 | 0 - 19 |
| 2 | Stack station 2 | 0 - 19 |
| 3 | Stack station 3 | 0 - 19 |
| 4 | Stack station 4 | 0 - 19 |
| 5 | Stack station 5 | 0 - 19 |
| 6 | Stack station 6 | 0 - 19 |
| 7 | Stack station 7 | 0 - 19 |
| 8 | Stack station 8 | 0 - 19 |
| 9 | Close molding frame | 0 - 19 |
| 10 | Apply vacuum to both molding frame chambers | 20 - 0 |
| 11 | Apply heat with full vacuum | 20 - 0 |
| 12 | Continue heat with full bottom vacuum, gradually release top vacuum | 10 - 0 |
| 13 | Continue heat with full bottom vacuum | 6 - 0 |
| 14 | Remove from heat, cool to about 50°C, hold bottom vacuum | 10 - 0 |
| 15 | Release vacuum, open molding frame, remove module assembly, place module on conveyor | 1 - 0 |
| 16 | Clean and inspect for next cycle | 5 - 0 |
| | | 74 - 51 |

Desired output: $$\frac{200{,}000\ \text{ft}^2}{\text{day}} \times \frac{1\ \text{module}}{2\text{x}4\ \text{ft}^2} = 25{,}000\ \text{modules/day}$$

$$\frac{25{,}000\ \text{modules}}{\text{day}} \times \frac{1\ \text{day}}{24\ \text{hr}} = 1041.7\ \text{modules/hr}$$

$$\frac{1041.7\ \text{modules}}{\text{hr}} \times \frac{1\ \text{hr}}{60\ \text{min}} = 17.36\ \text{modules/min}$$

At 95% yield, desired production rate:

$$\frac{17.36}{0.95} = 18.27\ \text{modules/min}$$

At 85% stream efficiency, desired capacity rate:

$$\frac{18.27}{0.85} = 21.50\ \text{modules/min}$$

No. of molds required:

$$\frac{21.50\ \text{modules}}{\text{min}} \times \frac{74.85\ \text{mold min}}{\text{module}} = 1609\ \text{molds}$$

No. of lines required:

$$\frac{21.50\ \text{modules}}{\text{min}} \times \frac{19/60\ \text{min}}{\text{mod/stack statein}} = 7\ \text{lines}$$

6. Direct labor, annual

| Description | | Number (a) | Rate | Hours | Total |
|---|---|---|---|---|---|
| Raw materials handlers | | 2 | 4.00 | 24x250 | 48,000 |
| Stack station attendants | 4x7 | 28 | 4.50 | 24x250 | 756,000 |
| Mold inspector, cleaner | 2x7 | 14 | 4.50 | 24x250 | 378,000 |
| Panel inspector, trimmer | 2x7 | 14 | 4.50 | 24x250 | 378,000 |
| Panel packager | 1x7 | 7 | 4.00 | 24x250 | 168,000 |
| Product storage, shipping | | 2 | 4.00 | 24x250 | 48,000 |
| Machine supervisor | | 7 | 6.00 | 24x250 | 252,000 |
| Inspection/trim supervisor | | 1 | 6.00 | 24x250 | 36,000 |
| Shift supervisor | | 1 | 7.50 | 24x250 | 45,000 |
| Shift mechanics | | 2 | 6.50 | 24x250 | 78,000 |
| Relief operators | 2x7 | 14 | 4.50 | 24x250 | 378,000 |
| | | 92 | | | 2,565,000 |
| Average 5% shift differential | | | | | 128,250 |
| | | | | | 2,693,250 |
| | | | | Use | 2,693,300 |

(a) Numbers correspond to items on production flow chart.

7. Capital equipment and buildings

Each line
Flattened oval carrousel. Mold cycle steps 14, 15, 16, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 on one side, steps 11, 12, 13 on other side, utilities, service connections, control valves in center.
Each line has 1609/7 = 230 molds.
Assume each mold, with attachments and fittings, requires 4 ft x 6 ft of space, allow average 1 ft between molds.
Carrousel width 6 ft, length 230 x 4 + 230x1 = 1150 ft, 1150/2 = 575 ft each side
Allow 10 ft wide x length of oval for center space.
Allow 10 ft x 20 ft for equipment for each stack station.

| | | | |
|---|---|---|---|
| Total area: | carrousel, services 575 x (6+10+6) | = | 12,650 |
| | stack stations 8x10x20 | = | 1,600 |
| | | | 14,250 $ft^2$ |
| | Conveyor to inspection area 3x250 | = | 750 $ft^2$ |
| | Aisles, 6 ft all around 6x575x2 | = | 6,900 $ft^2$ |
| | Per line | | 21,900 $ft^2$ |
| | Seven lines | = | 153,300 $ft^2$ |
| | Inspection and trim area 7x20x20 | = | 2,800 |
| | Packaging area 7x20x20 | = | 2,800 |
| | | | 158,900 |

Raw material storage

Hardboard, 3 weeks $\dfrac{6{,}250{,}000}{yr} \times \dfrac{1.01}{0.95} \times \dfrac{3}{52} = 383{,}350$ panels

Assume 8 ft stack, $\dfrac{0.120 \text{ in}}{\text{panel}} : \dfrac{8 \text{ ft}}{\text{stack}} \times \dfrac{12 \text{ in}}{\text{ft}} \times \dfrac{1 \text{ panel}}{0.120 \text{ in}} = \dfrac{800 \text{ panels}}{\text{stack}}$

$383{,}350 \text{ panels} \times \dfrac{1 \text{ stack}}{800 \text{ panels}} \times \dfrac{2\text{x}4 \text{ ft}^2}{\text{stack}} = 3834 \text{ ft}^2$

Double for aisles allowance 2x3834 = 7668, assume 8000 $ft^2$

Assume 8,000 $ft^2$ for each layer x 8 layers = 64,000 $ft^2$

Product storage, assume 1 week, assume 1/2 in stack height/panel,

stacks 8 ft high $\dfrac{8\text{x}12}{0.5} = 192$ panels/stack

$\dfrac{200{,}000 \text{ ft}^2}{\text{day} \quad \text{x}5} = 1{,}000{,}000 \text{ ft}^2/\text{wk}$

$1{,}000{,}000 \dfrac{\text{ft}^2}{\text{wk}} \times 1 \text{ wk} \times \dfrac{1 \text{ stack}}{192 \times 2 \times 4 \text{ ft}^2} = 651 \text{ stacks}$

$651 \text{ stacks} \times \dfrac{2\text{x}4 \text{ ft}^2}{\text{stack}} = 5208 \text{ ft}^2$ double for aisles allowance
2x5208 = 10,416 assume 10,000 $ft^2$

Building

| | |
|---|---|
| Manufacturing, trimming, inspection, packaging | 158,900 $ft^2$ |
| Raw materials storage | 64,000 |
| Finished product storage | 10,000 |
| | 232,900 |
| Office, 5% of 232,900 | 11,600 |
| Locker and lunch rooms, 5% of 232,900 | 11,600 |
| Maintenance shop, 40 x 100 | 4,000 |
| | 260,100 |
| | Use 260,000 $ft^2$ |

$260{,}000 \text{ ft}^2 \times \dfrac{\$30}{\text{ft}^2} = \$7{,}800{,}000$

Per line

| | |
|---|---|
| Stack stations \$50,000 x 8 | 400,000 |
| Molds \$1,000 x 230 | 230,000 |
| Carrousel 1150 ft x \$200/ft | 230,000 |
| Heating platen system 575 ft x \$500/ft | 287,500 |
| Vacuum system \$1000/mold x 230 | 230,000 |
| Cooling platen system $\frac{10}{36}$ x 575 ft x \$500/ft | 80,000 |
| Conveyors, inspection, trim, packaging stations | 50,000 |
| | 1,507,500 |
| Instruments and controls, spares, 30% | 452,300 |
| | 1,959,800 |
| Installation, 40% | 783,900 |
| | 2,743,700 |
| Engineering, 15% | 411,500 |
| Per Line | 3,155,200 |
| Seven lines | 22,086,400 |
| Auxiliaries, 10% | 2,208,600 |
| | 24,295,000 |
| Building 260,000 ft$^2$ @ \$30/ft$^2$ | 7,800,000 |
| | \$32,095,000 |

8. Working capital

| | | |
|---|---|---|
| Raw material $\frac{15}{250}$ (21,531,900 + 125,000 + 430,600) | = | 1,325,250 |
| + Work in process $\frac{1}{250}$ x 36,406,700 | = | 145,627 |
| + Finished product $\frac{3}{250}$ x 36,406,700 | = | 436,880 |
| + Receivables $\frac{1}{12}$ x $\frac{36,406,700}{0.80}$ | = | 3,792,365 |
| - Payables $\frac{1}{12}$ x 36,406,700 | = | - 3,033,892 |
| | | 2,666,230 |
| | | Use \$2,666,300 |

Appendix IX

MANUFACTURING COST ESTIMATE
SOLAR CELL ENCAPSULATION PROCESS
LIQUID CASTING TECHNIQUE

CALCULATIONS

1. Raw materials

Desired output $\frac{200,000 \text{ ft}^2}{\text{day}} \times \frac{1 \text{ panel}}{2 \times 4 \text{ ft}^2} \times (5 \times 52\text{-}10) \frac{\text{days}}{\text{yr}} =$

6,250,000 panels/yr

Assume 1% shrinkage and 5% rejects

Prefabricated solar cell arrays:

$$6{,}250{,}000 \ \frac{\text{panels}}{\text{yr}} \times \frac{24 \times 48 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 53.157895 \text{ million ft}^2/\text{yr}$$

Glass plates:

$$6{,}250{,}000 \ \frac{\text{panels}}{\text{yr}} \times \frac{26 \times 50 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 59.987208 \text{ million ft}^2/\text{yr}$$

Glass mat spacer:

$$6{,}250{,}000 \ \frac{\text{panels}}{\text{yr}} \times \frac{24 \times 48 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 53.157895 \text{ million ft}^2/\text{yr}$$

Aluminum foil:

$$6{,}250{,}000 \ \frac{\text{panels}}{\text{yr}} \times \frac{26 \times 50 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 59.987208 \text{ million ft}^2/\text{yr}$$

Vinyl spacer strip:

$$6{,}250{,}000 \ \frac{\text{panels}}{\text{yr}} \times \frac{6 \times 1 \times 1 \text{ in}^2}{\text{panel}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} \times \frac{1.01}{0.95} = 276{,}864 \text{ ft}^2/\text{yr}$$

Plastisol:

$$6{,}250{,}000 \ \frac{\text{panels}}{\text{yr}} \times [24 \times 48 \times 0.020 + \frac{24 \times 48 \times 0.005}{2} + 2 \times 0.5 \times 49.\ 0.048 +$$

$$2 \times 0.5 \times 4 \times 0.048] \ \frac{\text{in}^3}{\text{panel}} \times \frac{1 \text{ ft}^3}{1728 \text{ in}^3} \times \frac{1.01}{0.95} = 113{,}145 \text{ ft}^3/\text{yr}$$

Raw Material Costs follow:

Glass plates ($12.030/50 ft$^2$ x 0.090 in)

$$50.987208 \times 10^6 \frac{ft^2}{yr} \times 0.100 \text{ in} \times \frac{\$12.030}{50 \text{ ft}^2 \times 0.090 \text{ in}} = \$16,036,580/yr$$

Glass mat spacer:

$$53.157895 \times 10^6 \frac{ft^2}{yr} \times \frac{6.1 \text{ lb}}{17\times22\times500 \text{ in}^2} \times \frac{144 \text{ in}^2}{ft2} \times \frac{\$1.68}{lb} = 419,496$$

Aluminum foil:

$$59.987208 \times 10^6 \frac{ft^2}{yr} \times 0.001 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{2.71\times62.4 \text{ lb}}{ft^3} \times \frac{\$1.00}{lb} = 845,340$$

Vinyl spacer strip:

$$276,864 \frac{ft^2}{yr} \times 0.020 \text{ in} \times \frac{1 \text{ ft}}{12 \text{ in}} \times \frac{1.2\times62.4 \text{ lb}}{ft^3} \times \frac{\$1.50}{lb} = 51,829$$

Plastisol:

$$113,245 \frac{ft^3}{yr} \times \frac{1.21\times62.4 \text{ lb}}{ft^3} \times \frac{\$0.8326}{lb} = \underline{7,112,819/yr}$$

Total raw materials (excluding solar cell arrays) = $24,466,064/yr

Use $24,466,100/yr*

*Excludes solar cell arrays.

2. Utilities

Assume each casting frame contains 26 x 50 x $\frac{1}{2}$ x 2 = 1300 in$^3$ steel

Theoretical BTU to heat up, each cycle:

$$1300 \text{ in}^3 \times \frac{0.284 \text{ lb}}{in^3} \times \frac{0.107 \text{ BTU}}{\text{lb deg F}} \times (350-120)^\circ F = 9086 \text{ BTU/cycle}$$

Cost of theoretical steam for heat up, at $4/1000 lb steam

$$9086 \frac{BTU}{cycle} \times \frac{\$4}{1000 \text{ lb}} \times \frac{1 \text{ lb}}{1000 \text{ BTU}} = \$0.0363/cycle$$

| | |
|---|---|
| Assume cost to hold at temp equal to 1/3 theoretical heat up = | 0.0121 |
| | 0.0484 |
| Assume heating efficiency is 50% | 0.0484 |
| | 0.0968 |
| Assume equal cost for other utilities | 0.0968 |
| | $0.1936/cycle |

$$\frac{\$0.1936}{cycle} \times \frac{200,000}{8} \frac{panels}{day} \times \frac{250 \text{ days}}{yr} \times \frac{1 \text{ cycle}}{0.95 \text{ panel}} = \$1,273,684/yr$$

Use $1,273,700/yr

3. Freight

Assume no freight in on plastisol or solar cell arrays
Assume other raw materials received by truck, truckload is lesser of 40,000 lbs or 8x40x10 = 3200 cu ft, freight cost is $500 per TL.

Glass paltes

$$59.987208 \times 10^6 \frac{ft^2}{yr} \times \frac{0.100}{12} ft \times \frac{2.48 \times 62.4 \ lb}{ft^3} \times 40{,}000 \ lbs = \$966{,}994/yr$$

Glass mat spacer

$$53.157895 \times 10^6 \frac{ft^2}{yr} \times \frac{0.005}{12} ft \times \frac{\$500}{0.75 \times 3200 \ ft^3} = 4{,}614$$

Aluminum foil

$$59.987{,}208 \times 10^6 \frac{ft^2}{yr} \times \frac{0.001}{12} ft \times \frac{2.71 \times 62.4 \ lb}{ft^3} \times \frac{\$500}{40{,}000 \ lb} = 10{,}567$$

Vinyl spacer strip

$$276{,}864 \frac{ft^2}{yr} \times \frac{0.020}{12} ft \times \frac{1.2 \times 62.4 \ lb}{ft^3} \times \frac{\$500}{40{,}000 \ lb} = \underline{432}$$

$$982{,}607$$

Assume other freight in is negligible
Assume freight out is paid by customer

Use $982,600/yr

4. Packaging

Assume corrugated board packaging, pallet, and overwrap costs are $2.50 per 100 modules

$$25{,}000 \frac{modules}{day} \times \frac{250 \ days}{yr} \times \frac{\$2.50}{100 \ modules} = \$156{,}300/yr$$

5. Product storage, assume 1 week, assume 1/2 in stack height per panel, pallets 4 ft high $\frac{4x12}{0.5}$ = 96 panels/pallet

Assume 2 pallets/stack

$$\frac{200{,}000 \ ft^2}{day} \times \frac{5 \ days}{wk} = 1{,}000{,}000 \ ft^2/wk$$

$$1{,}000{,}000 \frac{ft^2}{wk} \times 1 \ wk \times \frac{1 \ stack}{2 \ pallets} \times \frac{1 \ pallet}{96 \times 2 \times 4 \ ft^2} = 651 \ stacks$$

$$651 \ stacks \times \frac{26 \times 50 \ in^2}{stack} \times \frac{1 \ ft^2}{144 \ in^2} = 5{,}877 \ ft^2$$

Double for aisle allowance 2 x 5877 - 11,754 assume 12,000 $ft^2$

## 6. Production

Casting frame cycle

| Step | Operation | Time, Min-Sec |
|---|---|---|
| 1 | Stack station | 0 - 19 |
| 2 | Place picture frame | 0 - 19 |
| 3 | Stack station 2 | 0 - 19 |
| 4 | Stack station 3 | 0 - 19 |
| 5 | Stack station 4 | 0 - 19 |
| 6 | Close, clamp casting frame | 0 - 19 |
| 7 | Tilt casting frame | 0 - 19 |
| 8 | Fill casting frame with plastisol | 5 - 0 |
| 9 | Apply heat, fuse plastisol | 5 - 0 |
| 10 | Apply cooling water, cool assembly | 5 - 0 |
| 11 | Open casting frame, remove module assembly | 1 - 0 |
| 12 | Clean and insepct for next cycle, return to horizontal | 5 - 0 |
| | | 23 min,13 sec |

Desired output: $\frac{200{,}000\ \text{ft}^2}{\text{day}} \times \frac{1\ \text{module}}{1 \times 4\ \text{ft}^2} = 25{,}000$ modules/day

$$\frac{25{,}000\ \text{modules}}{\text{day}} \times \frac{1\ \text{day}}{24\ \text{hr}} = 1041.7\ \text{modules/hr}$$

$$\frac{1041.7\ \text{modules}}{\text{hr}} \times \frac{1\ \text{hr}}{60\ \text{min}} = 17.36\ \text{modules/min}$$

At 95% yield, desired production rate: $\frac{17.36}{0.95} = 18.27$ modules/min

At 85% stream efficiency, desired capacity rate:

$$\frac{18.27}{9.85} = 21.50\ \text{modules/min}$$

No of casting frames required: $\frac{21.50\ \text{modules}}{\text{min}} \times \frac{23.22\ \text{frame min}}{\text{module}} =$

500 casting frames

No of lines required: $\frac{21.50\ \text{modules}}{\text{min}} \times \frac{19/60\ \text{min}}{\text{mod/stack station}} = 7$ lines

7. Direct labor, annual

| Description | | Number | Rate | Hours | Total |
|---|---|---|---|---|---|
| Raw materials handlers | | 2 | 4.00 | 24x250 | 48,000 |
| Stack station attendants | 3x7 | 21 | 4.50 | 24x250 | 567,000 |
| Plastisol attendant | 1x7 | 7 | 4.50 | 24x250 | 189,000 |
| Frame inspector, cleaner | 2x7 | 14 | 4.50 | 24x250 | 378,000 |
| Panel inspector, trimmer | 2x7 | 14 | 4.50 | 24x250 | 378,000 |
| Panel packager | 1x7 | 7 | 4.00 | 24x250 | 168,000 |
| Product storage, shipping | | 2 | 4.00 | 24x250 | 48,000 |
| Machine supervisor | 1x7 | 7 | 6.00 | 24x250 | 252,000 |
| Inspection/trim supervisor | | 1 | 6.00 | 24x250 | 36,000 |
| Shift supervisor | | 1 | 7.50 | 24x250 | 45,000 |
| Shift mechanics | | 2 | 6.50 | 24x250 | 78,000 |
| Relief operators | 2x7 | 14 | 4.50 | 24x250 | 378,000 |
| | | 92 | | | 2,565,000 |
| Average 5% shift differential | | | | | 128,250 |
| | | | | | 2,693,250 |
| | | | | | Use 2,693,300 |

8. Capital equipment and buildings

Each line

Flattened oval carrousel. Casting frame cycle steps 1, 2, 3, 4, 5, 6, 7, 8, 9 on one side, steps 10, 11, 12 on other side, utilities, service connections, control valves in center.

Each line has 500/7 = 72 casting frames.

Assume each casting frame, with attachments and fittings, requires 4 ft x 6 ft of space, allow average 1 ft between casting frames.

Carrousel width 6 ft, length 72 x 4 + 72 x 1 = 360 ft

360/2 = 180 ft each side

Allow 10 ft wide x length of oval for center space.

Allow 10 ft x 20 ft for equipment for stack stations 1, 2, 4; 20 ft x 20 ft for stack station 3.

| | | | |
|---|---|---|---|
| Total area: carrousel services | 180 x (6+10+6) | = | 3,960 |
| stack stations | 3x10x20+20x20 | = | 1,000 |
| | | | 4,960 $ft^2$ |
| Conveyor to inspection area | 3x200 | = | 600 |
| Aisles, 6 ft all around | 6x180x2 | = | 2,160 |
| Per line | | | 7,720 $ft^2$ |
| Seven lines | 7x7720 | = | 54,040 |
| Inspection and trim area | 7x20x20 | = | 2,800 |
| Packaging area | 7x20x20 | = | 2,800 |
| | | | 59,640 $ft^2$ |
| | | Assume | 60,000 $ft^2$ |

Raw material storage

Glass sheet, 3 weeks $\frac{6,250,000}{yr} \times \frac{1.01}{0.95} \times \frac{3}{52}$ = 383,350 sheets

Assume $\frac{2 \text{ ft stack}}{\text{pallet}}$, $\frac{0.100 \text{ in}}{\text{sheet}}$ : $\frac{2 \text{ ft}}{\text{pallet}} \times \frac{12 \text{ in}}{\text{ft}} \times \frac{1 \text{ sheet}}{0.100 \text{ in}} = 240$ sheets/pallet

Assume stack 4 pallets/stack

$$383{,}350 \text{ sheets} \times \frac{1 \text{ pallet}}{240 \text{ sheets}} \times \frac{1 \text{ stack}}{4 \text{ pallets}} \times \frac{26\text{x}50 \text{ in}^2}{\text{stack}} \times \frac{1 \text{ ft}^2}{144 \text{ in}^2} = 3605 \text{ ft}^2$$

Double for aisles allowance 2 x 3605 = 7210, assume 7500 $ft^2$
Assume 7500 $ft^2$ each for glass sheet, glass mat, aluminum foil, solar cell arrays; 2500 $ft^2$ for vinyl spacer strip; 20x20 for plastisol storage tank and distribution equipment: 4x7,500+2500+20x20 = 32,900 $ft^2$

Assume 33,000 $ft^2$

Building

| | |
|---|---|
| Manufacturing, trimming, inspection, packaging | 60,000 $ft^2$ |
| Raw materials storage | 33,000 |
| Finished product storage | 12,000 |
| Office | 12,000 |
| Locker and lunch room | 12,000 |
| Maintenance shop | 4,000 |
| | 133,000 $ft^2$ |

133,000 $ft^2$ x \$30/$ft^2$ = \$3,990,000

Capital equipment and building costs

Per line

| | |
|---|---|
| Stack stations 3x\$50,000+1x\$100,000 | \$ 250,000 |
| Casting frames \$2,000 x 72 | 144,000 |
| Carrousel 360 ftx\$200/ft | 72,000 |
| Plastisol fill system 72x\$1,000 | 72,000 |
| Steam system 72x\$1,000 | 72,000 |
| Cooling water system 72x\$1,000 | 72,000 |
| Casting frame closing, clamping, tilting, opening stations | 50,000 |
| Conveyors, inspection, trim, packaging stations | 50,000 |
| | 782,000 |
| Seven lines 7x\$782,000 | 5,474,000 |
| Plastisol storage and distribution system | 75,000 |
| | 5,549,000 |
| Instruments and controls, spares, 30% | 1,664,700 |
| | 7,213,700 |
| Installation, 40% | 2,885,500 |
| | 10,099,200 |
| Engineering, 15% | 1,514,900 |
| | 11,614,100 |
| Auxiliaries, 10% | 1,161,400 |
| | 12,775,500 |
| | 3,990,000 |
| Building 133,000 $ft^2$ @ \$30/$ft^2$ | \$16,765,500 |

9. <u>Working capital</u>

| | | |
|---|---|---|
| Raw material $\frac{15}{250}$ (24,466,100 + 156,300 + 489,300) | = | 1,506,702 |
| + Work in process $\frac{1}{250}$ x 36,528,500 | = | 146,114 |
| + Finished product $\frac{3}{250}$ x 36,528,500 | = | 438,342 |
| + Receivables $\frac{1}{12}$ x $\frac{36,528,500}{0.8}$ | = | 3,805,052 |
| - Payables $\frac{1}{12}$ x 36,528,500 | = | - 3,044,042 |
| | | 2,852,168 |
| | | Use 2,852,200 |